

# Photogrammetry of Cast Collection, Technical and Analytical Methodology of a Digital Rebirth

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Before the use of photography and digital projections, cast collections had a major place in Archaeology and History of Art studies. Replacing the original content, they permitted in different manners to touch the past in a safety and unobtrusive way: watch, touch and manipulate the cast allowed proactively students to learn the techniques of the ancient masters. Nowadays cast collections lay in university corridors or in museum storages waiting to be restored due to their material properties, the degradations of time, and the difficulty to use them in a course. Thinking about their past didactic roles, the Université Libre de Bruxelles wanted primarily a way to restore and preserve her antique study cast collection and, in the same way, give it a new sight as a nowadays collection study. For three months, in the same time of cast restorations, PANORAMA team has developed a photogrammetric workflow to produce and treat photographic shooting, texture delighting, point cloud reconstruction, meshing, retouching, simplifying, retopologizing, relighting and at the end of the whole process, web publishing. Through this paper the PANORAMA photogrammetric reconstruction methodology will be introduced and particularly the texture delighting process developed to enhance texture details and easily reintegrate models as a fully usable 3D asset in any 3D scene.

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Key words:

3D, Photogrammetry, Cast, Delighting, Workflow.

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## INTRODUCTION

As a precise surveying technique based on theories and optical experiments of Leonardo da Vinci [da Vinci 1970] around 1480, the principles of photogrammetry were born in the 17th century, when Desargues added the notion of vanishing points [Andersen 1991]. It was not until 1840 to move from theory to practice, under the aegis of François Arago [Arago 1939], who used this technique based on a daguerreotype, ancestor of the film camera. In 1849, modern photogrammetry was born from Aimé Laussedat's novel idea of using a set of photographs to measure the façade of the Hôtel des Invalides in Paris. This method has undergone many evolutions, especially under the aegis of Felix Tournachon, said Nadar, inventor of aerial photography, who in the 1860s, mounted in balloon to photograph the city of Paris for a map, both civilian and military. The surveying practice then had to wait for the material improvement developed during the interwar period completed later by the advent of satellite photography, the birth of computer science and the robotics.

Thanks to the contribution of digital photography and the computer and programming advancement in this field, offering the possibility of making and processing hundreds of shots by subject, photogrammetry

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seems to be, at first glance, a simple technique to set up and to reproduce inexpensive complex three-dimensional models such as cast collection from the Université Libre de Bruxelles. Nevertheless, the use of the photogrammetric techniques would make it possible to gather the whole of this collection in a virtual museum, easily accessible by all; but it requires many ancillary treatments essential to respect these constraints of accessibility and use.

## PHOTOGRAMMETRIC WORKFLOW

The current workflow involves many colorimetric enhancements and corrections of photographic data. The photogrammetric process is then followed by the geometric correction of the models, their weight and the constitution of PBR shaders from their textures. This linear workflow intends to make on internet the entire collection of plaster statues of the Université Libre de Bruxelles available for web browser. Fig. 1 summarizes these different steps.

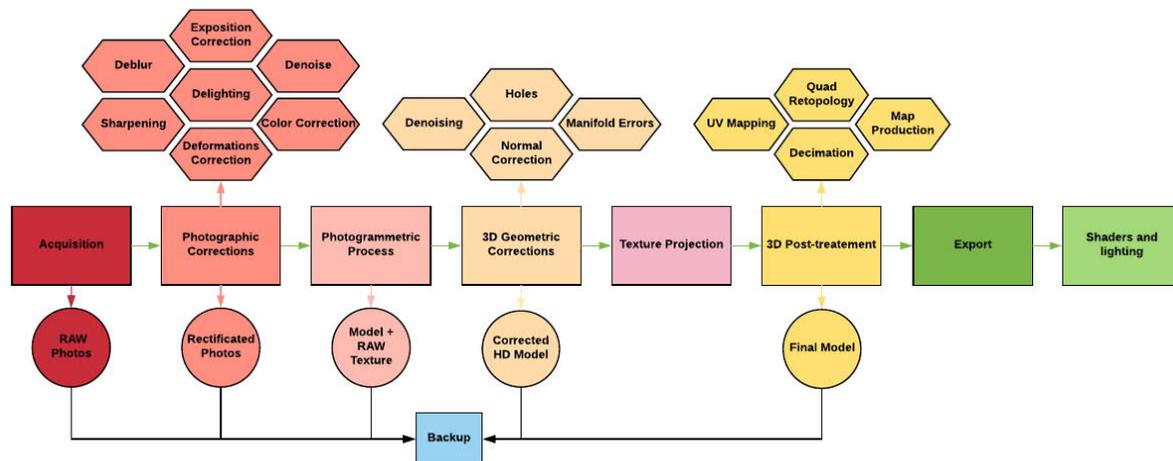


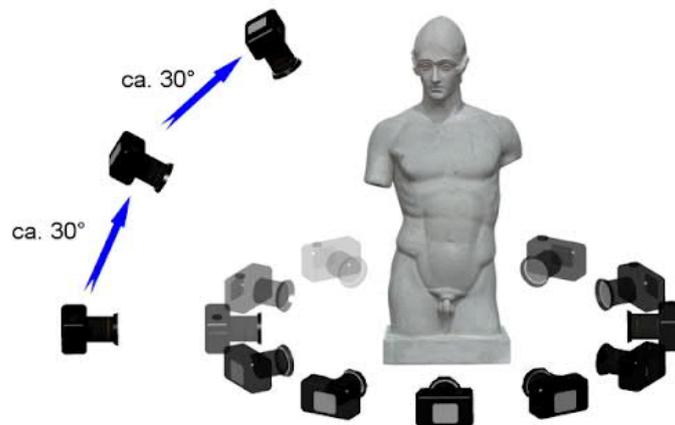
Fig. 1. PANORAMA Photogrammetric Workflow

## ACQUISITION METHODOLOGY

The methodology for acquiring three-dimensional reconstruction data of a work or architecture must be as logical as possible in order to limit the number of shots and unnecessary calculation time, while reducing the post-processing time in photographic and infographic. Several elements have to be taken into consideration:

- The purpose of the 3D model, which defines the needs in terms of texture and colorization, as well as the quality to adopt when taking data and the 3D treatments to apply a posteriori: paper publications, web publishing, virtual reality, reconstruction, schematic modeling, research, etc.
- The size of the real model: object of small, medium or large size
- The deadlines of the acquisition mission

- The accessibility of the real model and the logistics to deploy in order to obtain a complete model: constraints of the acquisition area (heavy or non-heavy equipment, impaired vision, reduced accessibility, etc.)
- The type of lighting (outdoor or studio) needed to obtain quality textures
- From these non-exhaustive constraints, it is possible to determine, in a more or less reliable manner, the methodology to adopt for providing the best model
- To allow accurate photogrammetric reconstruction with detailed texture, all the acquisitions were made using a prime lens on DSLR - 12Mpx Fuji S5 Pro in full manual mode with Nikkor Ais 35mm f2 - on stable tripod with 80% of overlapping between each pictures and a maximum cross angle of 30° between frames



*Fig. 2. Data acquisitions*

- The aperture was constant and combines the sharpest opening and the best depth of field. By the way, the data acquisition followed all those predefined photographic rules to obtain the best result during the photogrammetric alignment process:
- Never limit the number of pictures: always try to cover the entire subject with a 15 % to 20 % overlap between shots to facilitate the alignment procedure, but a safe shot should contain an overlap of 60 % to 80 %.
- Work on the lowest ISO measurement (64, 100 or 200) to avoid any noises in the resulting image.
- Use the highest resolution: this add more control points and give a better detection during the alignment procedure.
- Photogrammetry is not a panoramic shooting (static shooting). Unlike panoramic photography, the subject is fixed and the photographer must cover all its surface. The alignment process takes into account the background of the subject.
- Do not change the view angle more than 30° (in any axis). To make a larger angle change, it is necessary to produce intermediate shots.
- In order to identify important details when shooting, it is advisable to focus on them (an additional picture during the shooting process and not after).
- For full 3D subjects, it is necessary to take a complete cycle of pictures around the subject and not to take a spiral shot.

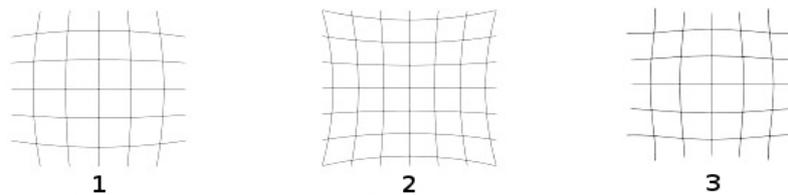
- To avoid any problem of Bokeh Effect and thus keeping maximum background information of the of the subject, it may be preferable to place the diaphragm aperture at least to 22 for a 35 mm lens, the light input will be minimum, the shutter speed will be reduced in long pause and so need the use of a tripod will be imperative!
- The picture focus point is made on the closest part to the lens of the subject.
- Depth of field will determine the number of shots: all fuzzy parts deserve the 3D reconstruction. These parts are useless and it is better to reduce the view angle to the perfectly developed zones and to adapt the pictures overlap.
- Working in autofocus mode is advantageous when it comes to a respectable size model. However, on small sizes subjects or in low light, it is necessary to disengage the camera and work in manual focus mode.
- Freehand shooting is quite possible, as long as the shutter speed is greater than 1/60 of a second. Below this shutter speed, it is better to attach a tripod and a wired trigger connected to the camera.

## PHOTOGRAPHY CORRECTIONS

The photographic correction or photographic pretreatment will depend heavily on the preparation of the shooting. Two important photographic corrections are noted: optical correction and color correction.

The majority of photographic lenses introduce deformations of several types. The straightening of these deformations is one of the logical steps of photogrammetry programs. Nevertheless, this geometrical processing by the photogrammetry programs is not sufficient and need the use of specialized programs which perfectly manage these deformations taking into account the couple camera and optical using a recognized reference database (LCP profiles).

Optical distortions affect all objectives, to varying degrees, depending on their quality. High-end lenses are, in principle, better corrected. These distortions mainly affect straight lines and can be classified in 3 classes:



*Fig. 3. The three types of lens distortions*

1. Barrel distortion: the lines are curved outward from the image, cylinder-shaped like a small barrel. This usually affects long-focus lenses such as zooms. On “fish-eye” lens type, this barrel distortion becomes circular.
2. Pincushion distortion: the lines, especially at the periphery, are curved towards the center of the image, like a cushion that is crushed. This usually affects short-throw lenses, such as wide-angle lenses.
3. Fish-eye distortion: equivalent to pincushion distortion, but more pronounced.

Every photographic shooting must be done with a reference image including a color chart to correct the white balance, the intensity of the blacks and calibrate the colors. It is essential to not neglect this step which will allow in post-production to recover real values modified by the intrinsic and extrinsic parameters of any camera.

## UNLIGHTING SCRIPT

To improve the images content, it is proposed to successively apply various operations as proposed by Schenkel [2017]. First of all, many pictures acquired during field surveys may have poorly exposed areas due to the acquisition parameterization and surrounding conditions (low light, specularly, etc.). The luminosity is thus corrected using a local gamma correction method. The local gamma factor is based on a mask defined as a low frequency monochrome version of the original image, avoiding to the chromicity of the image; while the deletion of high frequencies allows keeping the contrast of the image. Indeed, the impact of the mask is such that a pixel will be darkened especially as the value of the mask is large, and vice versa. So if the mask is a simple monochrome version of the original, the resulting image may lose its contrast. In contrast, the use of an image blurred to the extreme is to use a constant and a conventional gamma correction. This method has several advantages. The use of a low frequency mask causes progressive color correction through the image without artifacts. Extreme values are also preserved, as well as the pixels of the most complex regions. This correction makes it possible to relatively attenuate the highlights, as well as the main shadows, without introducing too much additional noise.

However, the results depend on the method to produce the low frequency mask. The adaptive filter introduced by Meylan and Süssstrunk [2006], which consists generally of a Gaussian filter limited by the edges in the image, determined with a Canny filter, give the best result. Indeed, mean and Gaussian blur results show more limited color corrections at the edges and brightness transitions; they introduces artifacts into the colorization (halos are noticeable at the level of luminosity transitions).

In a photograph, areas of blur are also often present, due to a problem of focus or autofocus, shaking when triggering, bad adjustment of the lens, a movement in the scene or insufficient brightness at the time of shooting. This results in a loss of quality at the object boundaries. Our experience in this case is to enhance the sharpness by reinforcing the high frequencies and thus increase the contrast at the edges without altering the colors or increase the imperfections of the image.

A simple method is to use an "unsharp masking" mask, a high-pass filter obtained according to the difference between the values of the original image and a version rendered blurred by using a low-pass filter. It is preferred to use image conversion in the HSV or CIE LAB color space, and restrict the approach to V or L components to avoid color distortion when sharpening. Thus, to obtain the image with accentuated details, it is sufficient to combine the initial image and this high-pass filter.

Finally a simple global increase in contrast is applied to restore the low hue losses inherent in previous processes. All of these corrections make it possible to obtain a noticeable visual improvement; by limiting overall noise increase to the initially darkest areas (shadows ...).

## POST-PHOTOGRAMMETRIC TREATEMENT

The polygonal model obtained at the end of the photogrammetric process is not usable due to the large amount of data to be processed (triangles of the 3D model and texture resolution). The HD model can only serve as a starting point for a workable and publishable model. The making of a final polygonal model is therefore not limited to the simple photogrammetric stage, because producing an untreated deliverable. It is important to correct certain aspects, at both the three-dimensional and the color level, by going through various stages of correction including

- Correction and cleaning of the polygonal mesh to eliminate artifacts such as unsmoothed spikes, excess meshes, polygonal aberrations, mesh holes, and manifold errors. Fig. 4 highlights these common artifacts in 3D modeling, as well as the results obtained after their treatment.
- Polygonal simplification of the model to reduce the amount of geometric primitives to make it usable on common computers or for a smooth publication in a web player.
- Retopology or streamlined Quad Polygonal Mesh [Bommes et al. 2012] for optimization in 3D rendering engines. The results of the simplification and retopology of a model are illustrated in Fig. 5 for a high resolution model.

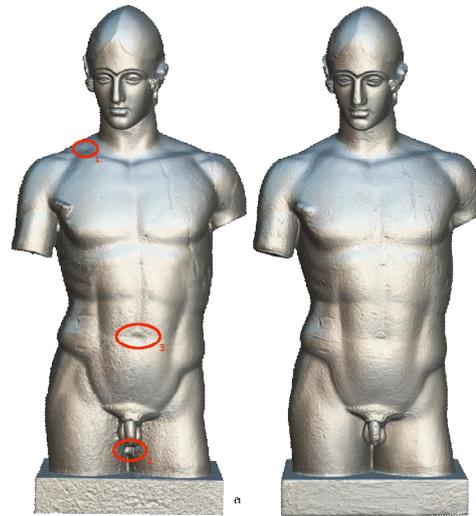


Fig. 4. Geometric model correction, tip smoothing and hole plugging can be observed between the uncleaned model (a) and the corrected model (b). Different problems are put forward on (a): 1. holes, 2. geometric artifacts and 3. deformations

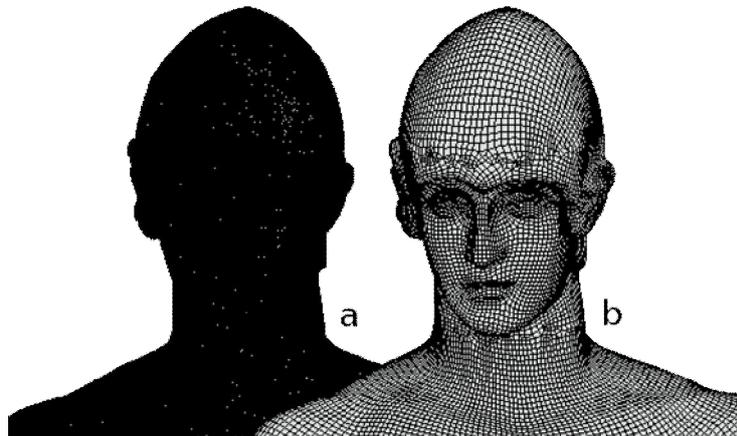


Fig. 5. Model decimation and retopology : (a) triangular model of average resolution (745.8 k points) and (b) retopologized model in quads (64.1 k points)

To be able to simplify the polygonal model, while preserving the impression of relief, the technique of normal mapping is used; it consists in transferring the elevation and inclination information from the surface of the geometry to a specific texture, called the normal map [Heidrich and Seidel 1999]. In addition to the use of a color texture, a graphics engine can emulate the shading and local geometric variations of the surfaces, thus making the appearance of relief and roughness.

To keep global surface modifications as well as local details (roughness), two normal maps are computed and merged. The first (see Fig. 6b) is obtained by projection of the normals at each point of the high-resolution model in the UV space of the textures; while the second (see Fig. 6c) is obtained by the colorimetric variations of the object (see Fig. 6a). Since the data represent directions, a simple linear interpolation or the individual processing of each

component does not make this combination possible; for this purpose (see Fig. 6d), it is preferred to use the fusion approach of Zioma and Green [2012].

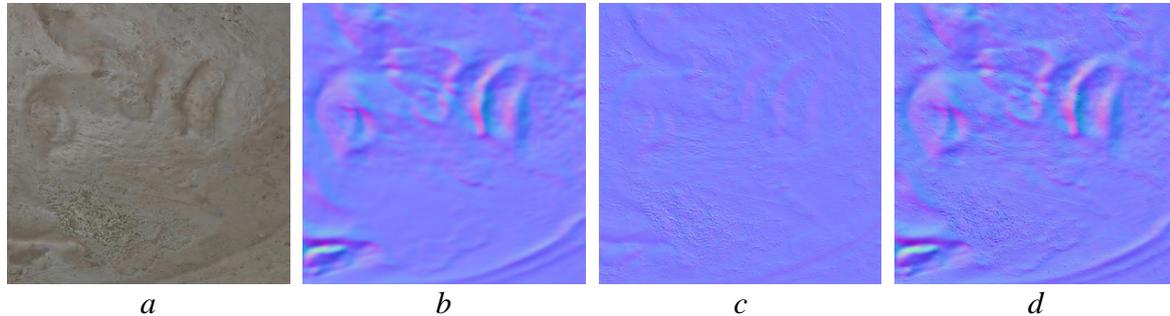


Fig. 6. The first normal (b) is obtained by projection of normals at each point of the high resolution model in the UV space of the textures; the second (c) is based on the colorimetric variations of the object (a); (d) result from the Zioma and Green fusion of (b) and (c)

Finally, a UV card mapping (UV Mapping [Mullen 2012]) of the model texture is made. The method consists in rationally unfolding the model in the form of a plane map; that is to say, keeping as much as possible the topology of the object avoiding cutting into a large number of pieces, allowing an optimal use of the surface of the texture and the possibility of carrying out easy colorimetric retouching. For this, a re-projection of corrected textures of the high-definition model is performed on the decimated and retopologized polygonal model, through a script developed through an automated inhouse blender script developed by Q. Elias and improved by S. Fachada-Dury. Fig. 7 illustrates the differences between standard and streamlined UV card plating. This makes it possible to obtain an exploitable, lightweight and optimal model on any rendering engine.

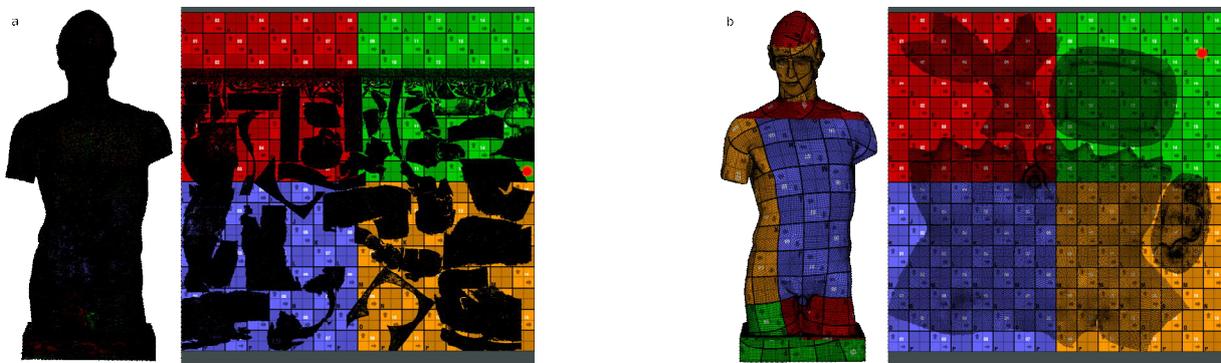


Fig. 7. Streamlined reprojection of textures : (a) texture and model obtained by photogrammetry and (b) decimated and retopologized model, as well as its rationalized texture.

## RESULTS

The acquisition and processing of the 13 models, made from a total of 4486 photographs, were spread out over 2 months of time and required the participation of a photographer for taking the images and the managing the lighting, a 3D graphic designer for 3D retouching, as well as the active participation and scientific contribution of a computer scientist to the development of the pipeline.

From these models, we have developed a real-time virtual museum scenography, available on the internet that anyone wishing to discover the collection of antique plasters from the Université Libre de Bruxelles can visit at their ease. Each virtual museum component has a cartridge with annotations and a direct link to the online high definition model. Fig. 8 gives a rendering of the virtual museum thus constructed.

However, without the different stages of processing, the virtual museum, which brings together all the digitized plasters, could not be completed, because of limitation of data volume imposed by the web rendering engine (250 MB maximum, model and textures included) and the quality/time ratio of loading the model on the internet for the user.



*Fig. 8. The virtual museum, including all the photogrammetric models, annotated to inform the user and made available on the internet*

## CONCLUSION

The project of digitization of the Université Libre de Bruxelles Cast Collection has focused only on the restored pieces of a particular chrono-cultural period representing only a tiny part of the inventory of acquisitions over time by our institution.

The pipeline is constantly evolving and adapting to many subjects using methods such as macro-photogrammetry, focus-stacking, RTI, virtual tours, virtual reality, 3D printing and CNC, lasergrammetry or drone survey. PANORAMA platform hopes to regularly expand the representative panel of the University's collection and to share it both with researchers and the public, and even extend it to external collections.

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# A Workflow for Fast 3D Documentation: An Experience on Medieval Architectural Fragments

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Currently, the knowledge of archaeological and cultural heritage artefacts is asking for the use of 3D models. Innovative tools constantly developed make it possible for the scholars to adopt an integrative approach accessible by everyone involved in the whole process of archaeological and cultural heritage surveying and representation.

The topic here discussed aims to investigate a workflow that allows a non-expert user to produce and manage a Structure from Motion 3D model, considering all the parameters that concern the reliability of the model and its scale. The proposed workflow regards the object size going from 20 up to 60 centimeters in architectural heritage field. Several examples will be presented to give a general frame of the possible results obtained by following a step by step procedure; the latter has been developed on several fragments now located in the Kyrenia Castle and surveyed during the international workshop “Reading and designing Kyrenia Castle” that was held in Cyprus Island. This study aims at identifying data capture standard process for the construction of 3D and 2D models in specific conditions, but frequent in surveying campaign. It refers to the concentration of the whole process in short time span, when only entry-level tools are available and survey operations involve non-expert user and a big number of objects.

A further development of this strategy could be to provide a fast 3D documentation shared and available through a database for archaeological excavations. The study focuses on the advantages, costs, and precision levels guaranteed by SfM, as well as 3D digital model as the fundamental element of the archaeological studies.

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## Key words:

SfM, 3D documentation, Kyrenia Castle, medieval fragment.

## CHNT Reference:

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## INTRODUCTION

This contribution concerns the proposal of a workflow that allows non-expert users to produce and manage “Structure from Motion” (SfM) 3D models [Visser et al 2019], considering all the parameters that examine the reliability of the model and its scale. Several architectural fragments located in the Kyrenia Castle were surveyed during the international workshop “Reading and designing the Kyrenia Castle, enhancing heritage in the historical landscape”, held from 6th till 13th of May 2018. The workshop applies innovative data collection methods analyzing one of the main architectural heritage sites of Cyprus Island, the Kyrenia Castle. Along with complete laser scanning and photographic survey of the castle and the Kyrenia Shipwreck, a detailed digital documentation concerns the archaeological materials of the Department of Antiquities, masonry types, mortars, and small-scale fragments. Students developed architectural design and restoration proposals for castle’s most critical areas and

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longtime discussed regional problems, lecturers, and professionals of various spheres from the above-mentioned institutions.

One of the topics involved in the workshop was the photogrammetric survey, as a very precise but procurable tool to collect accurate 3D structure from 2D data of small-scale objects. The workflow of fragments' digital survey, study and documentation were possible to be conducted by non-expert users

Non-expert users – students with a preliminary supervision of tutors – carry out the operation for fragments' digital survey, study and documentation. With a closer understanding of the program's key needs to produce complete 3D models, it is possible to use a uniquely tailored process to reach results with a desirable level of precision, ranging from fast digitally documented model to a more detailed one.

Students were able to test theoretical knowledge in practice. They could face firsthand with process' most important aspects: settings of the camera and the environment such are light, shadows, position and scale; acquisition strategies; programs' interface and settings. SfM technique is simultaneously quick and precise method that is reliable for future documentation of the architectural heritage on different scales [Lourakis et al. 2013; Kneip et al. 2016]. Collaboration between analytical and design groups within one workshop made it possible to use collected data to upgrade the quality and precision of the design process remotely. Similarly, students will be able to apply photogrammetry methods to their current and future projects. The synergy between students and tutors helped to identify possible process flaws and improve it by promptly applying the changes during the workshop to any of the workflow steps.



*Fig. 1. Archaeological fragments at Kyrenia Castle*

## HISTORICAL BACKGROUND

Due to its strategic location in the Mediterranean Sea, Cyprus Island acquired numerous military fortifications present as the evidence of many power fights for the island. Kyrenia castle, the most secure one of the region at the beginning of 12th century [Petre 2012] and for some period most likely the island's only one. Many rulers modified and reinforced the castle; however, it retained an early Byzantine church, an original tower within same period's walls, surrounded by Lusignan, Frankish and, later, Venetian grand constructions [Papageorghiou 2010; Soteriou 1935].

During the conquest of the island by Richard the Lionheart, Guy de Lusignan conquered the castle built by Byzantines in 1191 from the self-proclaimed emperor Isaac Comnenus. The history of Cyprus under the Lusignan rule continued till the end of the 15th century. Once a medieval fortification, Venetians strongly altered the configuration of Kyrenia Castle from 1489 to 1571 [Given 2005]. It got an impregnable structure with thick walls and tall round towers at its corners to withstand a possible Ottomans attack that never occurred [Camiz et al. 2016]. Thus, many fragments still present in the castle are reflecting a commandment of more than 100 years that was later followed by Ottomans [Megaw 1955].

Numerous objects found and presented inside the castle and on its walls are reflecting multiple influences that Cyprus Island and its fortifications experienced through the years (Fig. 1). First two fragments, that were proceeded during the workshop as well as other capitals present in the castle, were developed from the period from late antiquities to high middle ages and are a simplified version of such. The Corinthian capitals of the marble columns were taken from an older building elsewhere and placed there [Camiz et al. 2016]. Others include a classical Greek column base with ancient Greek script, Christian symbolic stone with Greek engraved words “Jesus Christ wins” that dates back to the 19th century, bell Aeolian-Pergamene capital or possibly a column base that may depict influences of Egyptian palm leaf motives, and a medieval 14th century herald at the entrance of a corridor leading to the courtyard of the castle is the coat-of-arms of Lusignan of Cyprus and Jerusalem (Fig. 2). Among others, there are spirally fluted columns, ottoman marble plates, anchors, symbolic stones, and numerous Corinthian capitals, some of them used in the structure of the church.



Fig. 2. Case studies

## WORKFLOW FOR NON-EXPERT USERS: CRITICAL ISSUES AND 3D DATA CAPTURE

Following the operative protocol proposed, it is possible to find solutions to problems most frequently faced in the process of photogrammetry that a non-expert user is usually not prepared to solve.

The workflow consists in the acquisition and processing stages.

The first stage is the most important one. A good photographic data capture affects the elaboration of high-quality 3D SfM model.

Unfavorable environmental conditions may sometimes occur during the survey acquisition phase, except if an indoor photo setting is prepared for objects small enough to be contained in it. Unfortunately, most of the time the shooting takes place outdoor, with various problems that derive from it, starting with the lighting control. The workflow related to this stage foresees the control of the following aspects: the morphology of the object, its sizes and location, the lighting, the camera settings, the shooting distance, and the metric references.

Depending on the morphology of the object and its fixed or mobile location, the very first important decision is about the creation of a complete 3D model of all parts, also an eventual base on which the object lies, or a limited survey of some areas. It is not possible to survey completely a fixed object. Thus, for example, the model of the Herald, which could not be moved because of its integration into the castle wall, happened to be deficient in data i.e. its back part. In another scenario, when working with mobile yet hardly movable objects, is preferable to conduct the surveying operations on its original location. This may happen when the part of an object is not particularly interesting or important (for instance, the bottom of the column base). On the other hand, when a complete 3D model is wanted, the user must rotate the object. The rule to follow is to include every part of the object on at least three photographs of the sequence in order to rebuild an accurate 3D model. The operation of rotation expected the utmost caution because by modifying the spatial relationships between the elements of the scene that could affect the processes of the photogrammetric software. One of the main aspects of the SfM process is, in fact, the recognition of key points in the scene, used by the software to orient the camera and reconstruct its 3D location. If the objects in the scene change their spatial relationships, the key points recognition does not happen. This problem has three solutions. The first is to recreate a neutral background to perform rotations of the object, such as a monochrome backdrop. In this way, the software will be deceived and will not notice the object's rotation, because there are no other recognizable elements in the scene except the object itself. Another solution uses the same principle with a post-processing supplementation work of masking the images to eliminate the background and only leave the subject itself. This is an effective method, albeit more laborious and longer than the first one. Finally, it is possible to process the photographs in different groups with a homogeneous background, by creating different sets for each rotation of the object and then by aligning and merging produced point clouds.

Even if it is more difficult, a complete documentation is clearly preferable. In the case of the architectural fragments of the Kyrenia Castle, the choice considers the above-mentioned factors: mobility or immobility of the object, and the interest of its hidden parts.

The object size and weight influenced previously mentioned point indirectly. Moreover, the sizes together with the location, affect the series of choices linked to the type of acquisition. If the object is very large, or when positioned at a hardly reachable place, the survey requires a ladder or any other similar support to photograph its upper part. The fieldwork project foresees this need in order to find the equipment and take into consideration the possibility of increasing acquisition times.

The lighting issue is very delicate, as light is an indispensable element for the purpose of photography [Bok et al. 2017]. The most favorable situation is the indoor shooting with diffused artificial light. Most of the time this cannot happen and one should optimize the situation in which he or she is forced to shoot. Apart from causing aesthetic and visual negative issues, shadows are the main problem related to lighting, whether the acquisition takes place outdoor or indoor without controlled artificial lights. In the most dramatic cases, and in conjunction with a shooting project that involves an object rotation, shadows can affect not only the texture but also the geometry of the 3D model. The problem of shadows must be assessed on a case-by-case basis. A good solution would be to shield the source of illumination, whether natural or artificial, so that, being the object in shadow, it does not produce harsh shadows itself. Sometimes this solution is not feasible due to the overall poor illumination of the scene, thus by screening the light source cannot diminish it. When it cannot be solved during the acquisition phase, some improvements can be made in post-processing. The later data processing includes this operation, making it more effective when images are in raw format.

Another issue related to lighting is the white balance, which varies depending on the color temperature of the light. To obtain models that in addition to having a correct geometry also have an exact chromatic component recorded in the texture, it is necessary to perform the white balance, either during acquisition or during processing phase. Some camera models allow setting the white balance before photographic acquisition. In other cases, is possible to modify it later, before processing the shots in the photogrammetric software. For the white balance, a color checker is necessary, and one should take the first picture of each set by placing the reference inside the scene, in front of the object, and remove it in the following shots. In the most desperate cases, one can use a blank sheet instead of the color checker, but the color rendering will be less precise. A more complex situation occurs when two sources with

different color temperatures illuminate the same object, for instance, the sun and an artificial light from different sides. In this case, it will not be possible to obtain a white balance that works for the whole object. The post-processing must predict the remove of one of the lighting sources or locally editing of areas with chromatic component anomalies.

Camera settings are one of the fundamental aspects that allow getting good photos and consequently good 3D models. Camera settings are a fine balance between ISO value, aperture and shutter speed.

ISO value represents the sensitivity of the photographic sensor and, therefore, influences the light that hits the sensor. Higher ISO value corresponds to greater sensitivity, brighter photographs, but also more noise defect. The strategy to avoid images with noise is to set a relatively low ISO value.

Aperture is a hole through which light travels into the camera body. At small aperture values, there is a larger aperture of the hole (for example,  $f/11$  is a smaller aperture than  $f/8$ ). The smaller aperture value is the more light is entering. However, the depth of field decreases too. The depth of field is a space range in images where everything is in focus. For the purposes of photogrammetry, it is important that the depth of field is large enough to take the entire surveyed object; otherwise, the sharpness lack will produce problems in the processing. Nevertheless, in this case, the strategy is to try to mediate between a small aperture value that reduces the depth of field, and a high aperture value that increases the light in the camera [Johannsen et al. 2017].

The last parameter to be set is the shutter speed or exposure time. This parameter influences the length of time during which the digital sensor inside of the camera catch the light. Longer exposure time produces brighter pictures but, if it is exaggerated, the risk is getting blurred photos, especially in absence of a tripod. The limit under which one should not go down to avoid blurred shots, in absence of a tripod, is  $1/60$  s. However, this value is subjective because it depends on the photographer's hand stability.

This brief description shows how complex the prior camera setting operation is. Most universal approach would be to set an intermediate starting ISO value (for example 100 ISO), camera to aperture priority (i.e. aperture remains unchanged during the shots and instead, shutter speed varies according to the lighting requirements), and choose an intermediate aperture (for example  $f/8$ ). Take a test shot to check the depth of field (i.e. if the object is in focus) and check the exposure time that is proposed; if the proposed exposure time is less than  $1/60$  s (or better  $1/100$  s) and if the entire object is in focus, it means that a perfect setting was found immediately. If not, it is necessary to intervene on one parameter at a time, maintaining the overall balance. For example, if the subject is not in focus and it required a greater depth of field, one should decrease the aperture. However, to ensure the same amount of incoming light, the shutter speed has to be increased. If it is already below  $1/60$  s and cannot be increased, ISO values will have to be raised. However, accordingly to the quality of the sensor, to avoid noise the ISO setting should be no higher than the 200 value, while this condition may cause longer exposure times, to prevent shaking blurred images, it will be necessary to use a tripod. Even non-expert users need to know the basics of photographic theory in order to independently manage camera setting and avoid automatic setup [Carpiceci 2012].

Shooting distance of medium and small objects is not particularly important. Instead, it becomes a fundamental variable in the acquisition by UAVs (Unmanned Aerial Vehicles) or when is necessary to have an extreme control of the texture resolution of the 3D model. In these cases, it is possible to choose a shooting distance, which, in relation to other parameters of the photographic equipment, allows knowing the final texture resolution (cm/pixel) in advance [Carnevali 2018]. The shooting distance, a priori estimation of which is impossible, affects the density of the point clouds.

The last aspect to consider during the acquisition phase is the positioning of a metric reference that will allow scaling of the surveyed object. It is possible to work in two ways: enter an external metric reference (scale bar) or take linear measurements directly on the object, if the geometry allows it. In both situations, it is a good practice to have two measures. Thus, the software uses the data redundancy to calculate the reconstruction error.

The metric reference should appear in most of the shots and must be immobile throughout the photographic acquisition. If the acquisition involves object's rotation, it is possible to maintain the reference for the whole first set of shots and remove it once rotate the object. In this way, the software will be able to reconstruct the object with its correct sizes.

The second phase concerns data processing.

Regardless of the software used, the user has to perform a series of steps that will allow obtaining 3D models from 2D images. The steps involved in the SfM process are the alignment of the camera, scaling of the object, creation of the dense cloud, polygonal surface (mesh), and finally, a textured model.

Before proceeding with the alignment of the camera, it is important to be sure to have produced a set of valid (sharp, not-blurred, with well-lit frames) images for the software. This control operation can be also manually. Some photogrammetric software products provide automatic control of image quality and propose the best ones to be included. However, before importing the images into the SfM software, it may be appropriate to apply a series of editing such as white balance, if it has not been done during shooting, and other settings to improve lighting conditions. For example, one should try to make shadows less evident. This operation consists in the decreasing the highlights and increasing the shadows value. As already mentioned, changes to the photo settings will produce better results if the shots were recorded in the raw format during their capture.

Once the images are ready, the SfM software makes available the first alignment step. In this step, the software analyzes imported images and positions them according to the camera location during the shooting moment with respect to the scene, exploiting the principles of projective geometry. The result obtained is a sparse point cloud. Through this point cloud, and activating the display of the camera positions, it is possible to understand if the software has oriented the shots correctly, and if the inserted photographs are enough to obtain a complete reconstruction of the object. The sparse cloud, as the name implies, is a model that has just few points. However, it is possible to verify the success of the final model already at this stage. If the sparse cloud presents evident lacks, not related to the low density that distinguishes it, there is a high chance that even the dense point cloud will be incomplete. Even if the sparse cloud is only an intermediate step, it can give some feedback regarding the success of the process before it is finished. If the software has problems aligning the images, it may be necessary to redo the photographic acquisition by adding elements to the scene. That will most possibly help the software to find more key points through which to orient the camera. If the sparse cloud presents evident lacks, it will be necessary to integrate more images that frame the area of the object that presents lacking.

After alignment, one can proceed with the insertion of the control points to scale the object and have a check on the reconstruction error. While for large-scale objects it is necessary to add coordinates acquired through a topographic campaign, for small-scale objects it is possible to use a scale bar. This tool allows scaling the object, indicating in the photos the extremes of the metric reference inserted in the scene and its measure. With two measures of this type, the software creates a report of calculation of the error. This allows performing a bundle adjustment that slightly corrects the camera position based on the control points entered. The user could scale later the object.

The next step is to create a dense cloud. The user can only give indications to the software on the type of depth filtering. An aggressive filter tends to not only smooth reconstructed surfaces but also to reduce the noise. That is the number of points that deviate from the ideal surface of the cloud which approximates the real surface of the object. On the contrary, a mild filter emphasizes the edges but produces more noise in the flat areas of the object.

Once build the dense cloud, it is possible to transform this discrete model into a continuous one and obtain a polygonal surface. In this step, the user can act on the decimation of the mesh, performing it, linking it to the intended use of the model.

Finally, the photographic texture completes the polygonal model, with the desired pixel resolution.

## BEYOND IMAGE-BASED MODELING: INTERPRETATION AND 2D REPRESENTATION

Reviewing and interpreting archaeological data involves written documents and representations that provide information about remained objects. Prior to the research, a correct approach to development of the archaeological models must first solve the following issues: the scale of digital model in terms of geometric and perceptive features; the metric accuracy of surveying data; aspects associated with dissemination, exchange, and fruition of archeological heritage.

Image-based methodologies have significantly changed the quality of information obtained during the acquisition phase. It does not only involve the operational aspects associated with the reconstruction of the drawings but a more general issue of how cognitive processes work in the world as a whole. The workflow has appreciably modified the whole approach to knowledge, based on extremely comprehensive and very detailed metric data and perceptive characteristics of the artifact. The initial surveying phase consists in data acquisition operations while data selection, interpretation, and restitution permit completion of the survey process. Data reconstruction is a complex phase,

closely linked to what an operator wishes to communicate with an analyzed object. This phase starts with a review of the acquired material and continues with an analysis of the artifact's unique elements; then, each student recognizes the different issues of the previously established objectives. Thanks for an ongoing progress in the field of technology, data acquisition operations, and processing procedures, the above mentioned and other digital instruments are more and more efficient, making it possible to achieve greater integration of heterogeneous data between different systems and, ultimately, better cognitively complete results.

The development of 3D digital modeling – obtained by using a photogrammetry method based on a 2D data – predict the obvious correspondence between the real object and its geometric abstraction. Creating 2D and 3D models make it possible to shift from a real object to its representation by selecting some of the endless outcomes regarding that specific object. Numerical and mesh models from photogrammetric digital survey are bases for 2D models sections extraction. However, our objective was to describe archaeological artefacts where it is not always possible to find well-defined edges or borders. Foreword, another issue is the representation of clearly visible but irregular discontinuities of the object. Classic representations of the plan and elevation of these objects provide documents; any ensuing studies and analysis often lay the groundwork for their restoration, maintenance or, more simply, management. In this phase, the operator's skills and its features could affect the highlight and communication of new aspects of archaeological fragments.

An important issue in the construction of 2D models of artifacts is the need to understand unique aspects of the context and representation of the scale. Traditional 2D models (plans, elevations, and sections) portray a quantitative and qualitative image of archaeological fragments of Kyrenia Castle, involving material, chromatic components and perceptive. The study of archaeological elements requires a focus on all of its characteristics, including superficial qualities, materiality, light effects, colors and their relation to landscapes. These characteristics determine the quantitative aspects of the elements analyzed: dimensions, geometries and formal traits. These models constitute the database used to perform processing operations, which provide a critical interpretation of these aspects. Expressing these qualities is a crucial part of the complex procedure used to acquire in-depth knowledge. This activity is, to some extent, subjective because it depends on the background and sensibility of who is involved with the artifact and analyses its material, morphological and natural components. Students build in-depth detailed models for each archaeological fragment in order to provide drawings (plan, scale, transversal section, longitudinal section in 1:10 scale) used in different kinds of analyses and interpretations ranging from the compositional geometric aspect to the study of surfaces' quality. To complete architectural representations photographic images integrated the geometric representation. These highly photorealistic outcomes improve the knowledge of the artifacts.

This activity develops a data system capable of providing a more objective metric, geometric and formal description of reality. The data system is like an open archive allowing users to verify and analyze considerations about their archaeological object; other similar models could increase it, creating a benefit through the integrated digital representation [Brunetaud et al. 2012].

## TESTING THE PROCEDURE: RESULTS AND REMARKS

The international workshop on Kyrenia Castle, as an on-site test of the whole workflow, brought to light some significant results in terms of user feedbacks.

By the end of the workshop, all participants must to complete an A3 page with a given layout containing specific data and elaborations. At each stage of the procedure, they have to fill the corresponding part of the A3 page to be aware of the role of that stage in the frame of the whole process (Fig. 3).

The first stage, data capture was synthesized on the A3 page by giving information related to the camera settings and number of pictures used for image acquisition. This information came with significant pictures describing the light and background conditions beyond the object itself. At the end of the first step, users acquire a basic knowledge about the camera and lens features (ISO, shutter speed, aperture, white balance, etc.) and how they could affect the result in SfM processes. Moreover, they have to set up the scene for shootings. Students had to evaluate which objects would be better to be include in the scene, a significant portion of a background to acquire more key features, or only an aseptical object that predict its rotation to acquire all its sides, including the bottom.

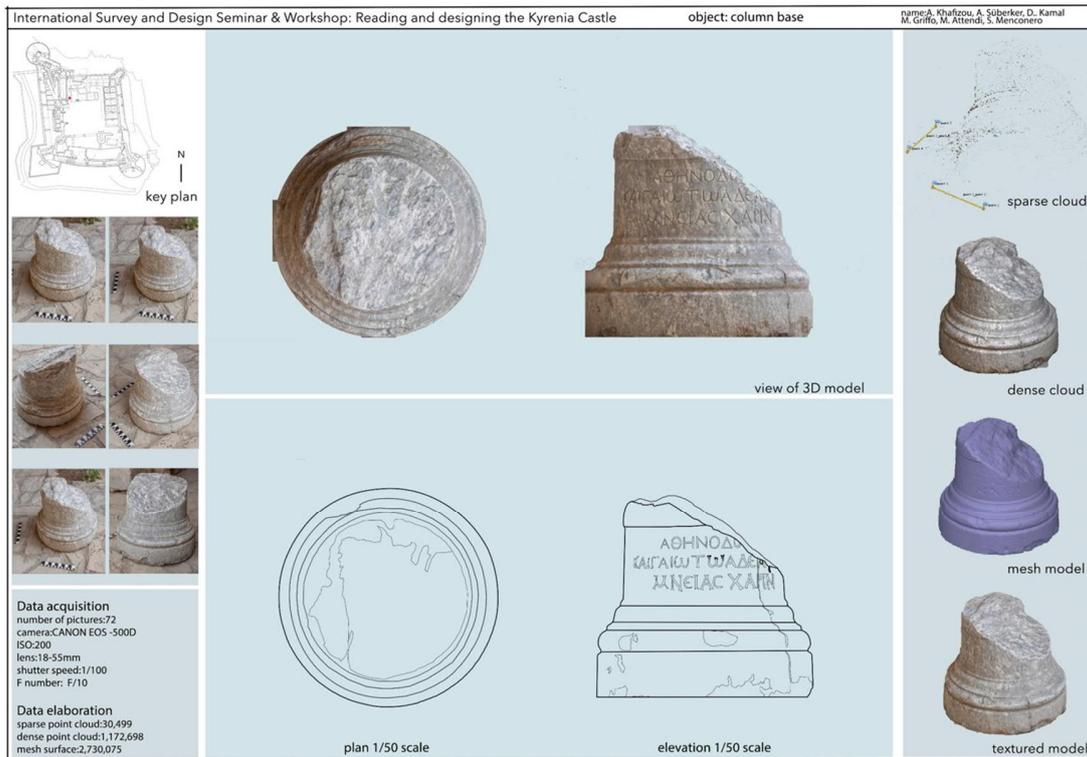


Fig. 3. Data capture and elaboration: from Structure from Motion to 2D representation

The second step is the data processing; during this stage, users can experiment the image post-production for SfM purposes and the photogrammetric basis that connects the 2D space of the image to the 3D digital environment. The result is the textured surface model. The main steps of the whole procedure -image alignment, sparse cloud generation, dense cloud generation, mesh model, textured mesh model- is their representation on the A3 page. The crucial goal at this stage is to maintain a level of accuracy that controlled by shared parameters such as the image quality estimation, the relative error in the 3D reconstruction of the scale bars inserted in the physical scene, and the scale of detail that the object must maintain to be used for a certain type of representation. These conditions allow further implementations of the model by giving the possibility to reproduce the experimentation according to the scientific method. It might be worthy to underline at this stage, the crucial distinction between quantitative data and their repeatable process and qualitative data coming from an interpretation of the observed phenomenon [Bianchini 2012]. The first two steps of the workflow - data capture and data processing - include quantitative information; for this reason, it is not required to the user to have a specific cultural background to approach the subject. The 3D point cloud as well as the textured model and the 2D orthoimages are the core of the documentation process. Once they pass the “metrical and geometrical validation” they can be shared among the community and used as a basis for further analysis in fields even substantially different from the ones strictly connected to the study of architectural fragments.

Things become dramatically different as soon as they are moving closer the third phase, data analysis and 2D drawings extraction. At this point, results collected during the workshop give the sense of the influence that cultural background has for the reading of architectural fragments. Participants were all familiar, at different level, with architecture in general and with the main composing rules of historical built heritage. This was useful to build a common ground to start with, but it did not make univocal the ideal decomposition of the object in its elements. For this reason, participants have to acquire theoretical and constructive information related to the fragment they had to draw; this allowed them to develop a specific knowledge about the object to ensure that their interpretation would be valid from a methodological point of view. This phase played a key role in 2D model production: at the end of the workshop, participants were able to recognize stylistic features of the fragments and to distinguish them from the degradation effects that affected both the surface of the material and the shape of the object. The final stage was a 2D representation of a horizontal plan, a vertical section and an elevation of the fragments.

The application of this procedure on a wider range of small-scale objects may encourage the democratization of information by contributing to creating a digital open archive containing raw and processed data connected to a specific topic. This would make easier the study of the heritage, especially in those situations in which the object is not physically available either due to the conservation restriction or due to the geographical distance.

With a full three days of training, a neophyte in digital data capture and processing learn a user-friendly workflow for the rapid documentation of objects. The future goal of the several attempts made in this direction [Martin-Beaumont et al. 2013; Cefalu 2013] will be the updating of the current archive systems in cultural heritage fields such as museum collections archive or documentation of findings on the archaeological excavation site, that are often available just for few days before being transferred to the warehouses.

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## AUTHORS’ CONTRIBUTIONS

All the authors contribute to the presented work. M. A. wrote “Beyond image-based modeling: interpretation and 2D representation”; M. G. wrote “Testing the procedure: results and remarks”; A. K. wrote “Introduction” and “Historical background”; S. M. wrote “Workflow for non-expert users: critical issues and 3D data capture”.

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# Combining Indoor Positioning Systems (IPS) with Structure from Motion (SfM) 3D Point Clouds in Cultural Heritage

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The benefits of using Geographic Information Systems in archaeology and cultural heritage are undeniable and the use of spatial data has been crucial in shaping a wide number of research fields. Nevertheless, the transition from “Geographic Information Systems” (GIS) to “Indoor Positioning Systems” (IPS) has not been adequately studied, despite the very promising uses of IPS in cultural heritage. This paper describes research conducted at the Digital Media Lab, Technical University of Crete. The use of an IPS is being tested on a monument in Crete, Greece, in combination with a 3D Point Cloud obtained by “Structure from Motion” (SfM) Techniques. The selected monument under study is located at the seafront of the 700 years old Venetian harbor of Chania and used to be the private residence of Ambassador R. Krueger who built it on 1890. The goal is to examine whether 2D data produced by IPS can be enhanced with 3D data from SfM in order to provide an enriched experience of navigation and personalized services customized to each user’s needs. Moreover, valuable insights for improving the architectural configuration of the monument’s interior can be extracted by documenting the exact position of each user in space in real time. Software used is *Indoor Atlas* for IPS and *RealityCapture* for SfM. The study was accomplished without the use of any hardware sensors – no beacons and no Bluetooth.

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## Key words:

Indoor Positioning Systems (IPS), Structure from Motion (SfM), 3D Point Clouds.

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## INTRODUCTION

Latest technology has enabled the development of spatial data advanced digital tools, thus creating an evident benefit for the urban cultural heritage sites.

*“In the ancient nuclei of many towns, these sites are like pieces of a puzzle that has become illegible; they pose serious problems of knowledge and documentation, in addition to problems related to monitoring their state of conservation.”*

[Gabellone 2009]

This paper focuses on the experimentation and future combination of two state-of-the-art technologies in the fields of spatial data acquisition and building modeling information on the same monument, the Ambassador’s Residence in Chania, Crete, which was built in 1890 as the private residence of Ambassador R. Krueger. The monument underwent major restoration in 2014 and since then functions as a boutique hotel.

In order to simultaneously conduct the two experiments, two distinct research groups were formed: the first group created a 3D Point Cloud from “Structure from Motion” (SfM), while the second group explored the potential of “Indoor Positioning System” (IPS) within the building. The first part of the paper presents the analysis, results and limitations of the SfM 3D Point Cloud process. The second part explores the IPS technology experiment within the building. The last section of the paper focuses on the potential of combining the outcome of the experiments into the

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same digital environment, aiming to produce a model that ‘can be used for the generation of a large amount of diverse information in both qualitative and quantitative formats’ [Rodriguez-Moreno et al. 2016].

## STRUCTURE FROM MOTION (SfM) 3D POINT CLOUD

The initial part of the research study conducted on the monument focused on creating a 3D Point Cloud produced with SfM (Structure from Motion) Techniques. Towards this goal, the limitations, effectiveness, and software efficiency had to be investigated. The research team used the following software: *RealityCapture*<sup>1</sup>, *Agisoft PhotoScan Professional*<sup>2</sup> and *Recap Photo*<sup>3</sup>. The 3D Point Clouds were created using a camera, a drone<sup>4</sup> and a video to jpeg images converter<sup>5</sup>.

### Experiment Setup Overview

Initially, building pictures were captured from different perspectives – both ground level and aerial ones – and were inserted into the selected software for further processing. The same procedure was repeated using different hardware and software for two reasons: on the one hand, different hardware was necessary to be used in order to get an accurate scanning of all the building parts. The drone was used during the scanning of the roof and upper building parts, while the cameras contributed to the scanning of the lower building parts. On the other hand, different software use served as the platform for further comparison and analysis. The various outputs were compared in terms of the process length, the process required to achieve the optimal result and the quality of the results. Supplementary pictures were taken and processed in, aiming to manage the preferred outcome.

### Experiment Process

The software used processes pictures and creates the 3D model by focusing on finding common points between pictures. Hence, the photos selected for import should be as focused as possible, and have at least 30 % overlap with each other. SfM

*“is most suited to sets of images with a high degree of overlap that capture full 3D structure of the scene viewed from a wide array of positions or as the name suggests, images derived from a moving sensor (‘motion’).”*

[Hopkins Nyimbili et al. 2016]

After the selection of the images and their insertion into the software, *Agisoft PhotoScan Professional* requires the following steps for the creation of the 3D model: aligning the points of the inserted pictures, creating the 3D Point Cloud, the triangulation of the point cloud union and texture application of the 3D model (Fig. 1).

*RealityCapture* follows a similar process. The steps are the following: photos insertion, alignment, reconstruction (mesh creation), reconstruction result, coloring, coloring result, reconstruction region set, reconstruction region mesh creation, reconstruction region mesh result, reconstruction region coloring, reconstruction region coloring result, and finally control definition and component consolidation (Fig. 2).

*Recap Photo* is similar to *RealityCapture* but offers additional editing options of the model (mesh editing, etc.), and further combination with other Autodesk software (Maya, 3ds Max). Unfortunately, the educational version of the software allowed the insertion of only 100 pictures per project. The software is cloud-based in all matters that regards the creation of the model, and operates with the charge of the user with credits, depending on the number of pictures each project includes. The difference of this software compared to the other two is that the 3D model is not created on the computer, but on Autodesk’s cloud server. Once the model is created, it is available for downloading from the cloud server (Fig. 3).

<sup>1</sup> Capturing Reality <https://www.capturingreality.com> (v.1.0.3.4658-demo version and 2-week-promo license)

<sup>2</sup> Agisoft <https://www.agisoft.com> Agisoft PhotoScan Professional 1.4.1 (30-day free Trial License)

<sup>3</sup> Autodesk Recap <https://www.autodesk.com/products/recap/overview> (v.19.0.0.38 free educational version)

<sup>4</sup> The drone that was used is DJI Matrice 100.

<sup>5</sup> The software that was used is JPG Converter (v.5.0.101 - free use)

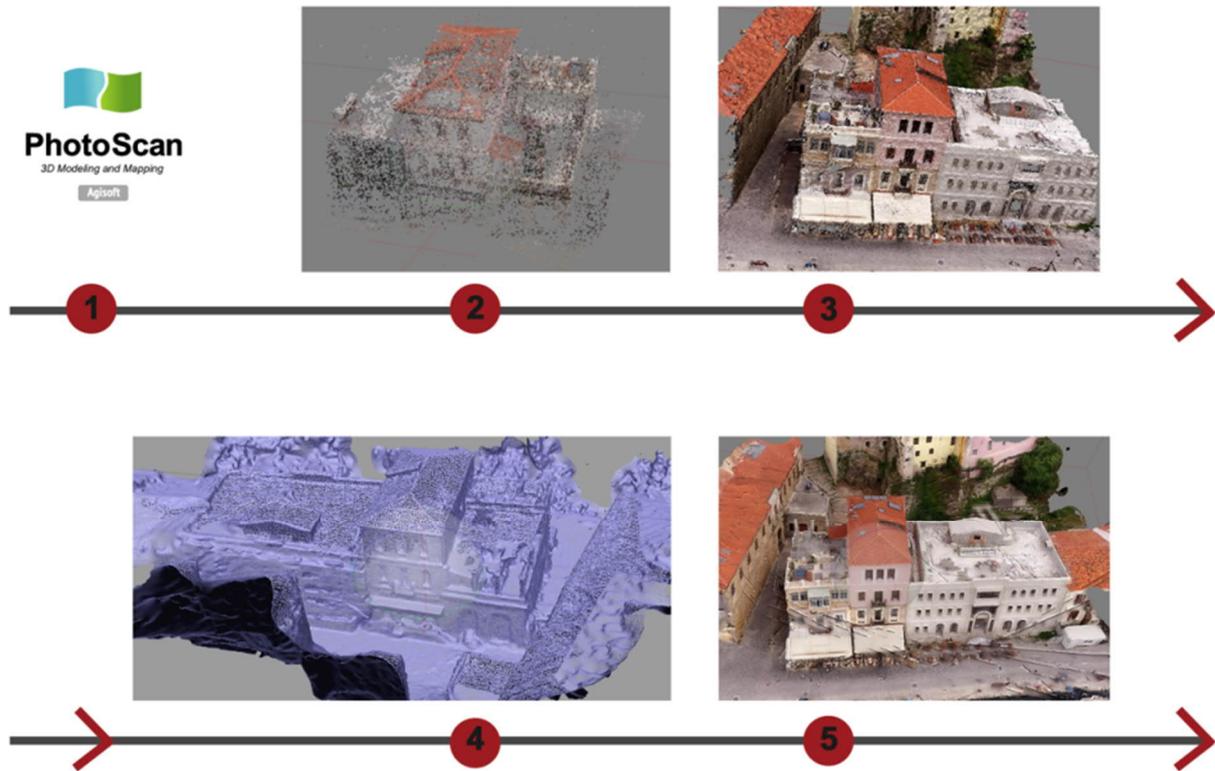


Fig. 1. Main implementation steps in Agisoft PhotoScan Professional. 1) Insertion of photographs, 2) 3D Point Cloud, 3) Dense 3D Point Cloud, 4) Mesh, 5) Final 3D model with Textures

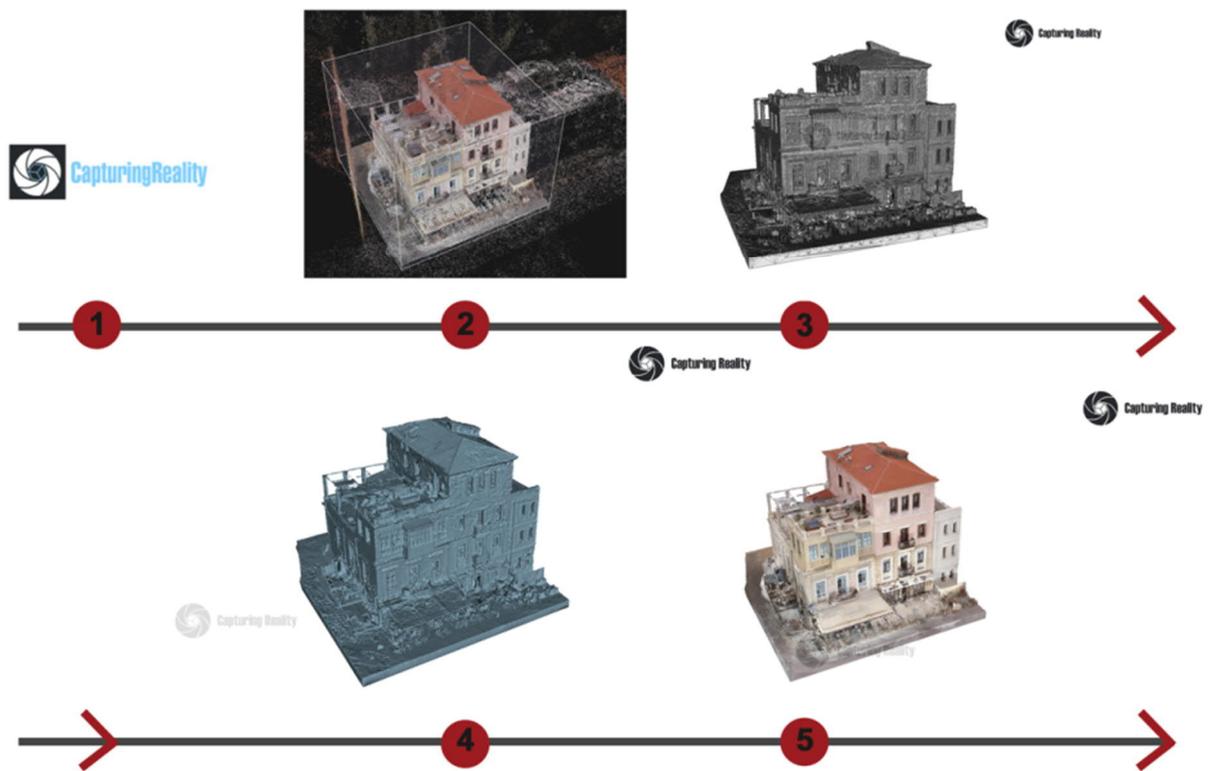


Fig. 2. Main implementation steps in RealityCapture. 1) Insertion of photographs, 2) 3D Point Cloud, 3) Mesh, 4) Solid 3D model without Textures, 5) Final 3D model with Textures

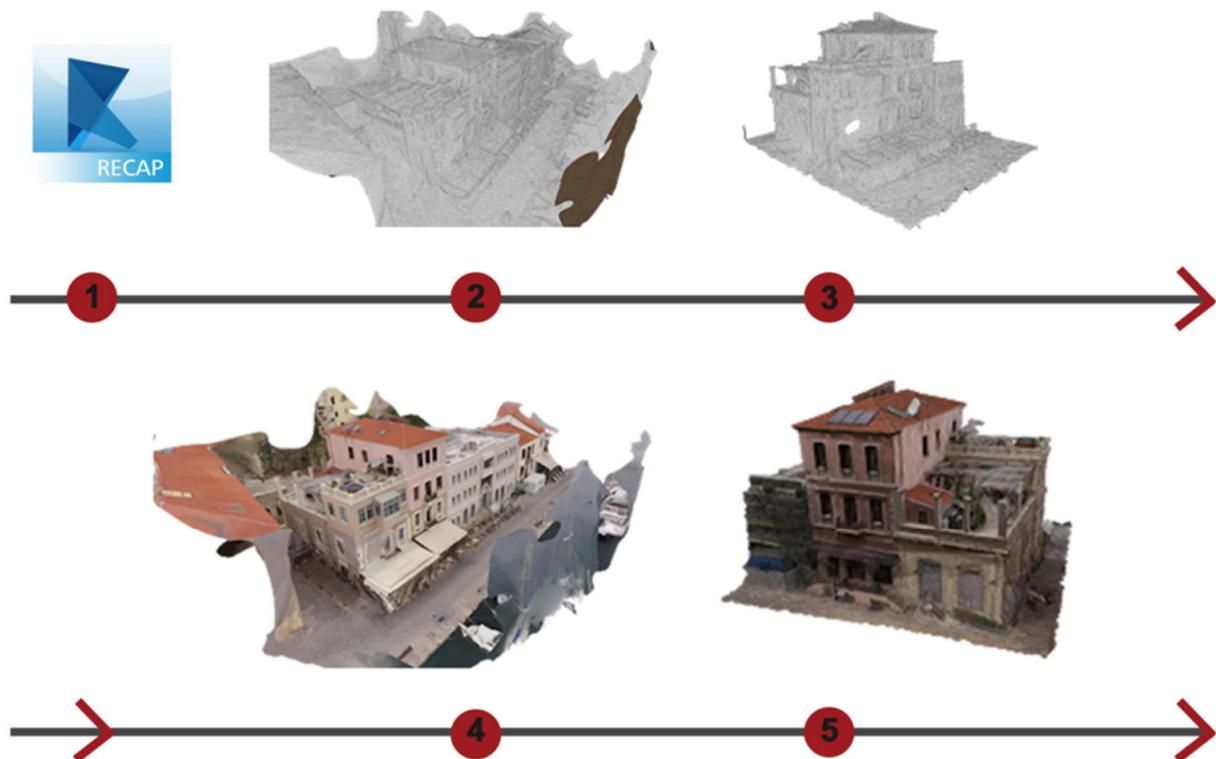


Fig. 3. Main implementation steps in Recap Photo. 1) Insertion of photographs, 2) Mesh, 3) Final 3D model with Textures and surrounding area, 5) Final 3D model with Textures

During the first attempt, the research team captured one building facade. Sixty-five (65) pictures were captured, inserted and processed by two distinct softwares, *Agisoft PhotoScan Professional*, and *RealityCapture*. The pictures had 42242 points each, with quality of image varying between 0.68-1.34 Agisoft Image Quality units, focal length 18 mm, and ISO 100. In *Agisoft PhotoScan Professional*, the steps and times that were needed were: Accuracy - Highest - 25 minutes, Build Dense Cloud - Medium - 30 minutes, Build Mesh - 15 minutes, Arbitrary, Dense Cloud, Height and Build Texture (Generic, Mosaic) - 15 minutes. The total time for the creation of the 3D model was approximately 90 minutes. The research team also created a video through *RealityCapture*. The main issues of the final model were a) the lack of pictures taken from different points that ended in lack of points at the final model and b) the fact that a percentage of the facade surface was covered with other objects (fabrics, pergolas, a/c inverters) that were equally translated as building elements into 3D point cloud and could not be isolated during the process.

During the second attempt, 267 pictures were taken from the three building facades, only from the ground level and inserted into *RealityCapture*. As a result, the model appeared slightly rotated from the horizontal level, and the ground level had to be corrected manually. The processing and settings time lasted approx. 60 minutes while the model creation lasted approx. 90 minutes. Many trials were conducted for the result optimization. The video exporting duration was approx. 60 minutes and the file size reached over 200 MB.

During the third attempt, the research team used a drone DJI Matrice 100<sup>6</sup> (Fig. 4), which flew for approx. 5-10 minutes, at small distance above the building with the camera inclined at 45 degrees. The drone path followed the building perimeter and then flew right above it, with the camera being vertical. The drone created two videos, lasting 194 seconds and 14 seconds. The video captured the hotel and the adjacent buildings, from an altitude of 15 meters for most of the time. As a result, the roof and the upper building level were well captured, while the lower levels did not appear properly.

<sup>6</sup> Camera of the Drone: Zenmuse Z3. Characteristics: 1) Sensor: CMOS, 1/2.3" - Max Pixels: 12.76 M, Effective Pixels: 12.4 M, 2) Lens: 3.5x Optical Zoom, 22-77 mm Equivalent - F2.8 (Wide) - F5.2 (Tele), FOV 92° (Wide) - 35° (Tele), 3) Photo Resolutions: L(4:3): 12 M, 4000x3000 and L(16:9): 9 M, 4000x2250, 4) Video Resolutions: UHD: 4K (4096x2160) 24/25p - 4K (3840x2160) 24/25/30p.



Fig. 4. Drone DJI Matrice 100

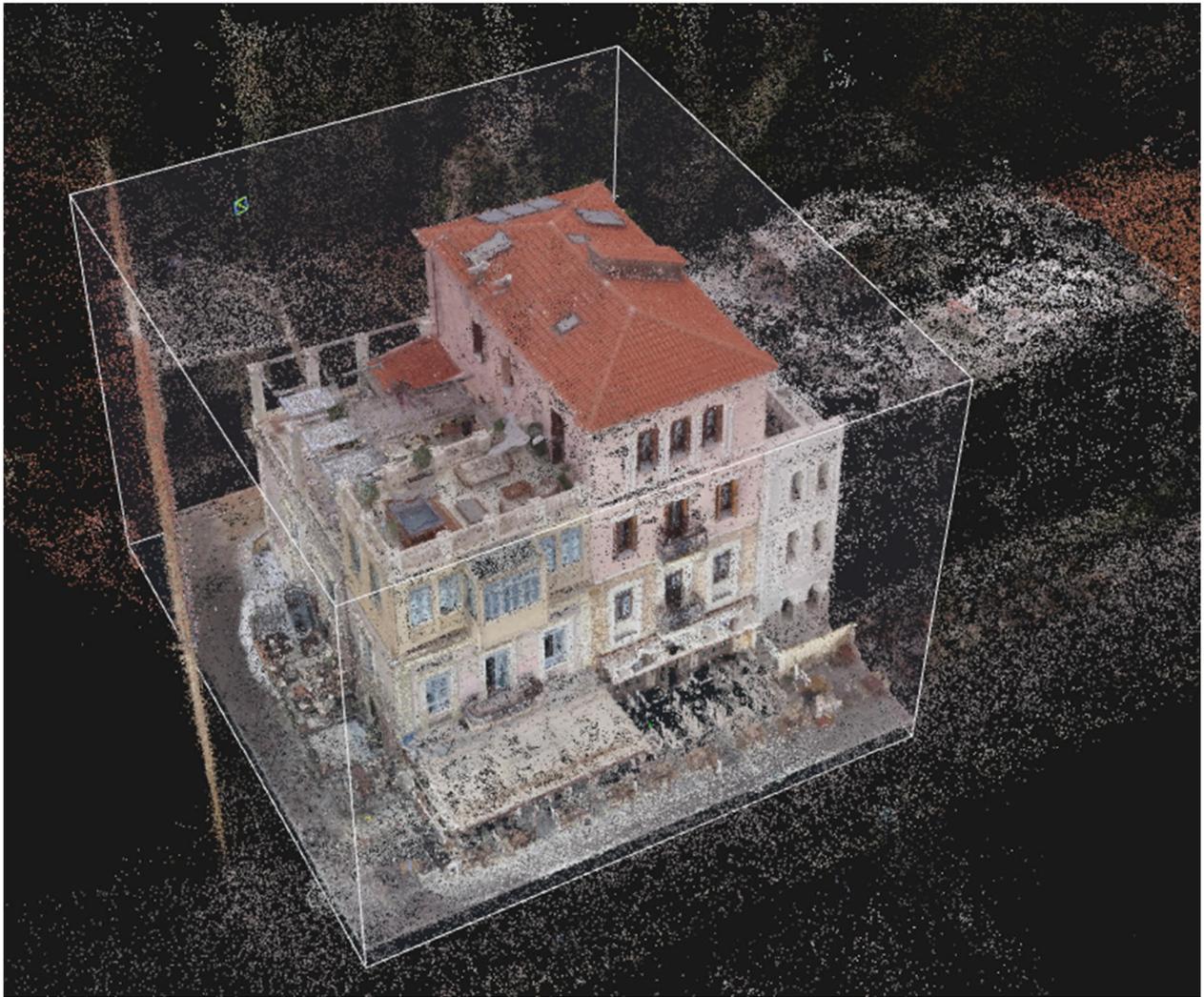
Due to the fact that the video could not be directly inserted in the software for the 3D point cloud, the team used the JPG converter for the extraction of frames number/second from the two videos. 310 pictures were totally extracted in jpeg format, each of them occupying around 1.6 MB (resolution 4096 x 2160 pixels / 96 dpi / 24 bit).

The 310 pictures were inserted into *RealityCapture* and the time for the construction of the 3D model was 80 minutes. The outcome was satisfactory for the roof and upper parts of the facades, but not for the lower parts of them, compared to the previous model extracted from ground level shots. Many areas appeared with no details and deformed. For *Recap Photo*, 100 pictures out of the 310 were selected, mainly depending on their overlap percentage, good focus, etc. The uploading time of the pictures (total size 170 MB) on the Autodesk cloud was approx. 30 minutes. The model required approx. 50 minutes in order to be completed and available for downloading and further editing on the computer. On the model (rcm format, size 61 MB) some issues were encountered on the canvas and the blank parts were filled. However, the outcome was not satisfactory in comparison with the *RealityCapture* model (as was expected due to the use of only 100 out of the 310 pictures) but it showed the potential for further improvement considering the various editing tools and settings that the software offers. Finally, for the *Agisoft PhotoScan Professional*, 100 camera pictures (resolution 1920x1080) were selected, 29041 points with quality varying between 0.923 and 1.80 Agisoft Image Quality units. All steps conducted at ultra-high resolution, except from the dense cloud that conducted at high resolution. The editing time lasted 2 hours and 40 minutes, and the outcome was satisfactory for the roof and upper parts of the facades, with some minor issues at the building lower parts.

During the fourth and more holistic attempt, the research team combined the 310 drone pictures with the previous 267 pictures from the ground level. 577 pictures were used in total and were processed by two software, *Agisoft PhotoScan Professional*, and *RealityCapture*. In *RealityCapture*, in order to achieve a better matching of the different sets of pictures, 34 control points were used and the process lasted 7 hours. The outcome was improved due to combination of ground level and aerial pictures, and was superior to the result from *Agisoft PhotoScan Professional*, but still had quality issues.

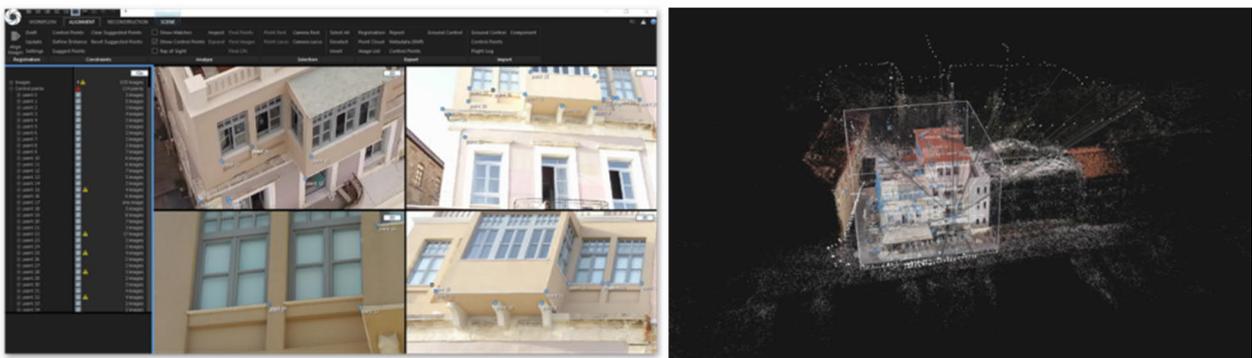
Following to that, the research team created two separate models from the ground level pictures and the aerial ones correspondingly and combined the produced models with markers. 121 camera pictures were selected (resolution 1920x1080), and the model was completed in 3 hours and 20 minutes. Unfortunately, the result model was not satisfactory.

During the sixth attempt, 445 new pictures were taken and, along with 190 pictures from the drone, were inserted in *RealityCapture* (635 pictures in total), with their resolution between 8.8 MP (drone) to 13.5 MP. Due to the fact that different cameras were used and that pictures were taken on various dates, the software failed to combine the different parts into only one component initially. The research team implemented the matching by adding control points, which installed common points between different captures. After a long trial-error process that lasted 4 hours and the insertion of 90 control points in total, the point cloud component was completed, and after another 150 minutes the mesh was created. The outcome was radically optimized, as the number of pictures combined and the control points installed was the maximum of all previous attempts. (Fig. 5)



*Fig. 5. 3D Point Cloud in Reality Capture*

Finally, the research team made a last attempt with a 2-week-promo license Reality Capture, similar with the previous one, that used 631 pictures and 114 control points (Fig. 6). The time needed was 7 hours, and the outcome was adequate.



*Fig. 6. Control points in RealityCapture*

What is really interesting, here, is that the increase of control points did not improve the model, especially in the front facade that encountered the bigger issue.

Table 1. List of specifications of each attempt.

Number of Trials	Camera/ drone	Number of pictures	SfM Software	Time of Process	Outcome
1st (one facade only)	Camera	65	<i>Agisoft PhotoScan Professional</i>	1 hour and 30 minutes	Not satisfactory, holes at areas that needed more pictures from different directions
			<i>RealityCapture</i>		
2nd (three facades)	Camera	267	<i>RealityCapture</i>	2 hours and 30 minutes (creation of video: 1 hour extra)	Not satisfactory, lack of pictures from high altitude
3rd (roof and three facades)	Drone DJI Matrice 100	310	<i>RealityCapture</i>	1 hour and 20 minutes	Satisfactory regarding the roof and facade upper parts Not satisfactory (compared to previous attempts) concerning the lower parts
		100	<i>Recap Photo</i>	2 hours	Not satisfactory in comparison to Reality Capture model Potential for further optimization
		100	<i>Agisoft PhotoScan Professional</i>	2 hours and 40 minutes	Satisfactory concerning the roof and upper parts of the facades / Issues regarding lower parts
4th (roof and three facades)	Drone DJI Matrice 100 and Camera	577 (310 and 267)	<i>RealityCapture</i>	7 hours	Improved model, due to combination of ground level and aerial pictures Improved in comparison with Agisoft PhotoScan Professional
			<i>Agisoft PhotoScan Professional</i>		
5th (roof and three facades)	Drone DJI Matrice 100 and Terrestrial pictures	121	<i>Agisoft PhotoScan Professional</i>	3 hours and 20 minutes	Not satisfactory
6th (roof and three facades)	Camera Drone DJI Matrice 100	635 (445 and 190)	<i>RealityCapture</i>	6 hours and 30 minutes	Radically improved model, due to extra pictures and control points
7th (roof and three facades)	Camera Drone DJI Matrice 100	631 (441 and 190)	<i>RealityCapture</i> (2-week-promo license)	7 hours	Satisfactory

## Proposed 3D model improvement techniques

After seven attempts, the 3D model optimization technique was established to the following steps: 1) Usage of one high-resolution camera, with big sensor, good lens (prime, not zoom), and polarized filter (for the elimination of reflections from windows and glassy surfaces)<sup>7</sup>, 2) picture overlapping at least 30 %, 3) picture capturing of the whole building besides the more focused ones, 4) picture capturing on cloudy days in order to avoid shadows and reflections, 5) picture capturing in the minimum time possible on the same day, in order to avoid position change of movable objects and shadow differentiation on each facade and finally 6) in the case of use of drone, camera specs should be finetuned (i.e. resolution, stabilizing system), pictures should be taken from a low level and should include as much building view as possible.

## INDOOR POSITIONING SYSTEM (IPS) PROCESS

The second part of the research study presents the implementation process of an “Indoor Positioning System” (IPS) within the monument interior space, aiming to track user location within the building and record real-time visitor flows. The research team intended to create a digital building map providing the accurate location of each occupant who navigates into the building’s interior space via smart mobile phone device.

In this framework, the team used the indoor positioning platform Indoor Atlas and its component mapping application, Indoor Atlas Map Creator 2, which operates on Android OS.

### Implementation Process Overview

The implementation process consisted of the following three steps (Fig.7): 1) The team signed up and uploaded floor plan images aligned with geo-coordinates on the world map to the link: <https://app.indooratlas.com> (setup), 2) users downloaded and installed on their mobile phones the Indoor Atlas Map Creator 2 application. Then they logged into the account and generated signal maps from collected data while they physically moved in the space (mapping). 3) The Software Development Kit (SDK) was generated.

The research team accomplished the above-mentioned process using the mobile device ‘Samsung S7 Edge’.

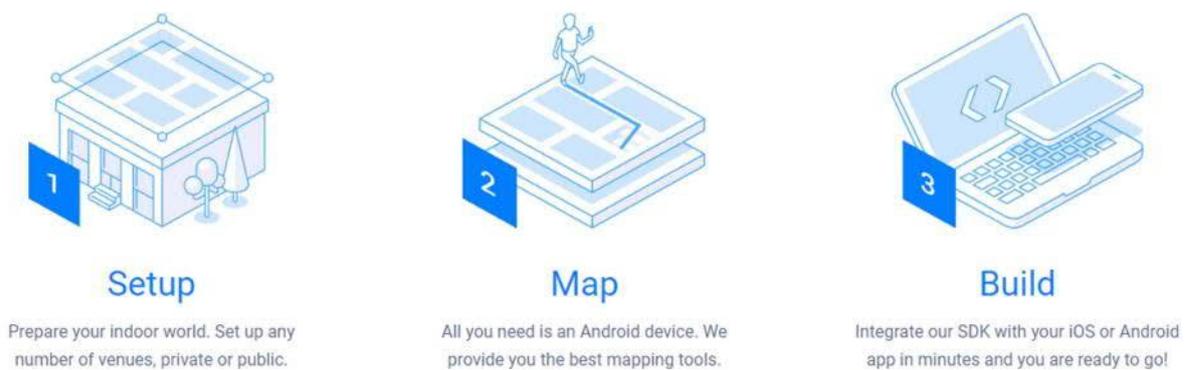


Fig. 7. Implementation steps (©IndoorAtlas)

### Implementation Analysis

*“The indoor positioning system (IPS) is composed of two components. The first processes the raw data from the inertial measurement unit (IMU), which ends up in relative position coordinates, which are passed to the second component. The second component transforms the relative coordinates into global ones and brings them into the context of the building”*

[Bernoulli et al. 2010].

IPS technologies collect data using the smart device sensors from the surrounding environment such as magnetic, beacon, Wi-Fi etc. with the help of the user’s relative movement while moving physically into the space. The selected data are then compared against digital maps, which have been produced by algorithms on Indoor Atlas

<sup>7</sup> A camera should have at least an 1 inch sensor or preferably an APS-C sensor and high resolution (e.g. about 24 MP). With a larger sensor area it’s much easier to capture detailed images under any light conditions and avoid any loss of quality. Wide angle (e.g. 24 mm) and fast (e.g. f2) lenses will allow more light capturing and combined with a stabilization system will contribute in blurry images avoidance. A camera with 4 K video capabilities will be very convenient in extracting high quality images from the video.

cloud platform so as to obtain user's location. The best location accuracy can be achieved when more data have been observed [IndoorAtlas 2019a]. After several tests and detailed recording of the steps and the constraints presented during the implementation of the mapping application, the research group achieved the creation of a digital building map for two levels of the hotel accommodation. Below, these main constraints and therefore key points of attention are gradually presented.

### 1. Floor plan alignment with geo-coordinates

The main requirement of the setup step is the alignment of the building satellite image with the correspondent vector plan. However, the map provider isn't always able to show accurate photos of the case study building as in some geographic regions satellite images have low quality or insufficient details. If building's outlines are not clear, the floor plan alignment risks to be imported inaccurately and at a wrong scale [IndoorAtlas 2019b]. If the satellite view does not provide enough details to accurately align the image, the "Exact coordinates" alignment method can be used to achieve maximum superimposition of the two maps [IndoorAtlas 2019b].

Another significant factor is the simultaneous uploading and alignment in case of multiple floor plans of the study space. In this case, floor plans must be meticulously uploaded with the same and correct alignment, paying particular attention to elevators, staircases and escalators, so as to achieve smooth and easy floor transitions. It is equally important to provide the "Floor Number" when the building has multiple levels as the correct floor number determines the exact superimposition of various levels.

### 2. Hardware requirements and settings

The devices' requirements for creating a digital map according to the official website are: a) Android software and OS version 5.0 or newer and b) Hardware sensors (accelerometer, magnetometer, gyroscope). The list of devices that are able to accomplish the mapping process is narrower than the one suitable for the positioning.

On the other hand, for the positioning mode, Indoor Atlas SDK can run on both android devices which support API level 21 (Lollipop) and on iPhone 4S or newer models. Indoor Atlas automatically uses all available sensors to provide the best possible positioning experience, but for the most accurate one, gyroscope and magnetometer are needed [IndoorAtlas 2019c].

Another crucial point is that the Wi-Fi scanning features in the device settings must be enabled and have a strong signal, otherwise the recorded paths are not optimal and the resulting map quality is affected.

Low Wi-Fi scanning quality or frequency, which varies across phone models [IndoorAtlas 2019d] lead to continuous MapCreator warnings pop-ups on the device's screen that hinder the mapping process and demand more time mapping on the same areas to achieve satisfying performance [IndoorAtlas 2019d]. In order to ensure that the scaling was right, the distance between two waypoints was measured with the use of MapCreator2, during the Mapping Process.

### 3. Mapping Process (Fig. 8)

The mapping process requires the digital juxtaposition of the two-dimensional drawing with the global coordinates. The key points for this alignment are called waypoints and are identified by manually tapping on the digital map while standing at the physical space corresponding point. The most important part proved to be the correct alignment of the first waypoint. According to Eric Piehl

*"After the first fix is computed, the heavy-duty algorithms kick in and very accurate positioning estimates are calculated using the geomagnetic and other methods."*

[Piehl 2018]

During the mapping process, the following errors occurred: 1) some waypoints were placed at inaccessible physical spots. As a result, the user was not able to recognize them with accuracy when proceeding to checking in that points, or run out of time because there is a five-minute time limit while recording a path, 2) pop-ups appeared on the device's screen warning on the fact that the compass heading didn't match the path. Positioning the phone face up during the whole mapping process solved the issue. According to the software developers *"if such a path is stored, the resulting map quality will be low and thus likely leads to red mapping analytics and inaccurate positioning."* [IndoorAtlas 2019d] 3) it proved difficult to achieve an accurate location positioning of the user after the first mapping within the building. As recommended in official Indoor Atlas support solutions webpage [IndoorAtlas 2019d] an ideal Wi-Fi mapping coverage cannot be achieved with the recording of a single pass through a bigger space or even a corridor. Especially in wider spaces it is recommended parallel paths to be recorded in order to achieve the best geomagnetic coverage. (Fig. 9)



Fig. 8. Mapping process a) insertion of waypoints; b) creation of path; c) creation of digital map



Fig. 9. 'Magnetic mapping coverage' map

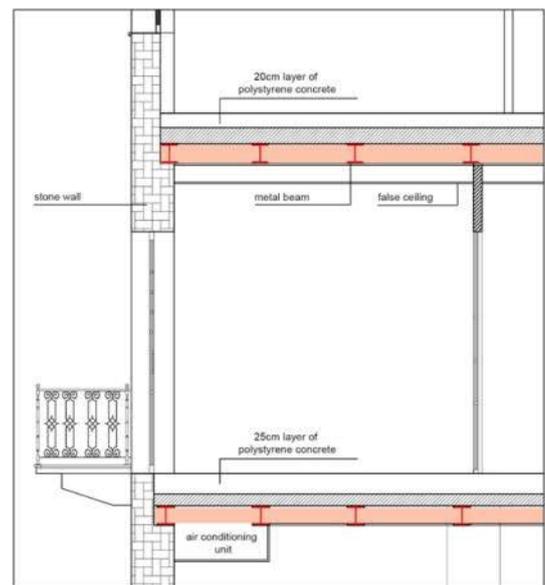


Fig. 10. Case Study Building Section, scale 1:50

#### 4. Building structure

The building structure also played a key role in the mapping in terms of materiality. The material that has the ability to interact with the magnetic field of the earth and create a unique magnetic landscape is steel. However, the walls of the specific building are stone-built. The research team conducted an analysis of the structure prior to the experiment implementation to reassure that the mapping attempt would be successful. It was proved that during the building restoration and reuse as a hotel, metal beams covered by false ceilings were used for the reinforcement as shown in the image (Fig. 10).

According to the study, important elements that contribute to the mapping process in the building are lifts. In addition to the metallic elements contained in the lift, another factor that can contribute is the barometric pressure resulting from the change of level. The barometer sensor of a smartphone can detect even the smallest changes in atmospheric pressure, which is modified whenever the user moves in a vertical direction (via a lift or a ladder).

## COMBINATION OF THE TWO METHODS

This case study was used to allow the establishment of a new spatial framework where the two methods will interrelate, influencing and feeding into each other. On the one hand, SfM is an already applied photogrammetry method producing imagery using low-cost metric cameras and aims at the sparse reconstruction of the building's point cloud model [Hopkins Nyimbili 2016]. On the other hand, the Indoor Positioning System is a new method, currently in beta version, that produces Human - Building Interaction quantitative data and tracks in real time the users' location within the building. SfM produces geometry through scanning, while IPS uses Internet of Things to extract informational data of the building. While both methods are developing technologies and none has reached its full potential, they remain completely different, both in terms of their operational process and the outcomes. Their only common point is that they both relate to the geometrical attributes of the building and extract information on it. We argue that the SfM produces form, while IPS deciphers the function of the building.

What is the optimal way to combine these two methods into a common spatial framework? And how would this combination contribute to the establishment of the building-as-a-service model? The integration of the two methods into a novel three-dimensional space can be executed in a twofold way. Firstly, as a means of integrating building function into form. In that framework, the relative user position and movement paths extracted by the multiple two-dimensional IPS layers can be geo-referenced with the 3D point cloud model created by the SfM method. What is necessary, here, is the development of new BIM libraries in order to take into consideration the level of detail required and the simplification of the models.

*“The BIM offers a distinctive factor, which does not exist in any other field: a multi-layered spatial character in the third or even fourth dimension, when historic phases of the building are considered. These 3D models must allow a continuous transition in scale between the survey of the whole architectural complex and its individual elements.”*

[Rodríguez-Moreno et al. 2016]

Secondly, as a means of enhancing the user experience within the building, through the combination of the two methods with VR applications. Given that user location is trackable through the use of smartphones, IPS applications are able to calculate the building occupancy, densities and flows real-time. At the same time, the geometry of user flows can be referenced within the same axis system of the SfM model. Combining the above, we could envision a VR environment, where the user would be able to virtually visit the building's best or most populated spots, and experience the space at different moments of its life.

## CONCLUSIONS

In this study, an approach to experiment and combine SfM and IPS methods in the current state-of-the-art architectural technologies is demonstrated on the monument of Ambassador's Residence in Chania, Crete. The usefulness and limitations of the methods are presented in the two experiments. The contribution of the current study consists in overpassing the operational application limits of the existing technologies and trying to juxtapose a 'relative, image-space coordinate system' into a 'real-world, object-space coordinate system'. However, the two technologies have significant limitations, such as the need for multiple cameras in the case of SfM, or the use of specific Android Smartphones for the building mapping in the case of IPS. In future studies, it is important to experiment with the application of a building-as-a-service model that will function as a knowledge container of the building and as an innovative platform for future VR applications.

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# Graffiti Photogrammetry, Extracting the Signs from the Walls of the Kyrenia Castle

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Contemporary photogrammetry, with the use of high-resolution sensors and correct shooting procedures, allows getting details far from the common level of perception of the human eye. This can be particularly useful in the use of macro and micro details, but it can be extremely useful also in specific situations when even quite large elements are difficult to be read and interpreted. In the case of the walls with Graffiti in the Kyrenia Castle, Cyprus Island, where a set of representations showing ancient ports, harbours, ships and boats it was extremely difficult to be read in the actual lighting situation. This is also a case study where the lighting situation is not ideal and where some logistic issues have caused the missing of a proper portable set of lights. Thus, with specific solutions, taking care about the shooting technique using state of the art camera and lens (Nikon D800e and 60 mm F2.8 Micro Nikkor), it was possible to take a well-detailed set of images to be used in the creation of an ultra-detailed 3D model of a whole set of graffiti. From this, using 3D rendering and multimedia techniques a set of proper elements has been created for dissemination and teaching purposes, allowing to enhance the perception of these artworks in the waiting for a new and more advanced permanent lighting system. The presentation will bring all the technical data from this case study, the detailed description of the lesson learned, suggestions about how to enhance the results from such a survey campaign and the complete workflow from shooting to multimedia creation/exhibition.

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## Keywords:

Graffiti, Photogrammetry, 3D model, Multimedia, Museum.

## CHNT Reference:

Stefano Bertocci et al. 2018. Graffiti Photogrammetry, Extracting the Signs from the Walls of the Kyrenia Castle.

## INTRODUCTION

The Kyrenia ship is the wreck of a 4th-century BC Greek merchant ship. It was discovered by Andreas Kariolou, – a diving instructor – in November 1965 [Katzev 1981]. A mission guided by the archaeologists of the Pennsylvania University recovered all the remains of the hull and various fragments from the nearby area from 1967 to 1969; this operation was coordinated by Michael Katzev [Swiny and Katzev 1973]. These operations represent one of the very first experiences in nautical archaeology. Even if heavily damaged, the relic of the ship still presents enough parts to describe the whole hull and give all the elements needed to hypothesize its reconstruction [Steffy 1985]. After its restoration, in 1970, it was placed inside the Kyrenia Castle [Enlart 1899; Jeffery 1935; Hill 1948; Petre 2010], Kyrenia, Cyprus Island [Katzev 2008]. The room chosen for the exhibition is enriched by graffiti from the 13th century, representing various ships. A quite specific choice that somehow emphasizes both the exhibited elements: the ship and the Graffiti. Thus, the large size of the ship, and the visiting solution, based on a gallery elevated on pillars, reduce the visibility of the graffiti part. The museum, in facts, presents a quite traditional exhibition solution, with the ship placed more or less central to the visitors path, the access to the room is done by the “aerial” gallery, passing in front of the series of Graffiti, which, even if showing a specific story and worth of a certain attention,

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results hard to be noticed and quite unreadable by the people visiting the museum. The present paper, deriving from the Round Table “Round Table: Advances in Image-based 3D Reconstruction and Modelling (SfM/MVS<sup>1</sup>)” in the 23th CHNT Conference, Vienna, 2018, presented in the form of a linear description the trouble/problem solving process adopted for this survey, in the hope to give a contribution to others in facing similar situations and bringing back similar positive results.

## THE GRAFFITI IN THE CASTLE, A HISTORICAL OVERVIEW

Ship graffiti scratched on plaster or stone surfaces are delicate. Often, they are partially preserved due to environmental factors and careless restoration projects. Their accurate and speedy documentation is highly important for their future, making possible to bring on studies aimed to the understanding of their technical details as well as their interpretation as historical social behavior. The curvature of the buildings, inaccessibility, light conditions (sometimes too strong or too feeble), the presence of multiple graffiti, sometimes over imposed one another or drawn over large areas are all problematic obstacles for the recording of these specific artworks. The technique used in documenting ship graffiti in this test, if compared to traditional methods previously attempted<sup>2</sup> (hand tape measurement, tracing or photography), provided an accurate speedy documentation of a significant sample, in a solution that may be extended to all the 19 ships graffiti, galleys as well as fish motifs, as a whole document, found over a plastered surface measuring up to an height of 4.20 meters from the level of the gallery. The ship graffiti mentioned in this study, by a lucky coincidence, is located on the second-floor level southern wall inner face of the Kyrenia ship wreck’s exhibition gallery, which was once the living quarter of the Lusignan (1192-1472 AD) and Venetian (1472-1570 AD) rulers. Generally, dating and identification of the ship type of the graffiti is challenging. However, as they are often on the walls of a building, on castle cisterns or churches, the building they are made on represents the “terminus post quem”, the date after which the graffiti were made. Therefore, in this example from the Kyrenia castle, it is possible to give an estimated date standing between the 13th and the 16th century AD. Further studies of the “scene” with nautical archaeologists and medieval historians may provide further interpretation of the ships drawn, defining if they may be considered a part of a historical event or something coming from some sort of casual drawing. At the present state of the arts in the knowledge about these artworks, it is only possible to increase the number of interpretations, while the complete certainty about their vicissitudes seems a quite difficult goal to reach. However, the historic resource of Makarias who mentions galleys reaching Kyrenia in 1374 and attacking the castle is food for the thought [Şevketoğlu 2017: 185] in rising up a possible relationship between an adventurous and dramatic event and the appearance of representations celebrating it.

## PRESENT SITUATION

Entering the room dedicated to the Kyrenia Shipwreck, the remains of the boat emerge from the space, the visitors enter passing by a transparent tunnel, walking on a balcony. This U-shaped intervention allows a 180° degrees turn around the wooden structure of the ship, which is illuminated in subtle lighting. Standing behind the glass element from the narrow tunnel is probably not the most comfortable situation. A different approach to the setup of the room will be hopefully a step forward for this museum. By fortunate coincidence in museum design it is possible to read a specific paper presented in this same volume of proceedings [Ceylanlı et al. 2018]. For now, for the visitors, the focus of the attention is the ship. They barely pay attention to any other thing around; the surface of the wall is in most of the cases completely ignored. The lighting on the walls does not help, it is quite homogeneous, flattens down the traces in the plaster while the spotted and mostly brown surface completes the result in making the graffiti quite hard to be noticed.

## A DIFFICULT PHOTOGRAMMETRY

During the “Kyrenia Castle Workshop” in 2018 [Bertocci et al. 2018], while taking care about the digital survey of the large Castle hosting the museum [Camiz et al. 2017], the idea about making a specific and “in depth” survey of the ship and of the graffiti developed. For both these operations, photogrammetry turned out to be the better solution in producing a detailed and well working 3D model. Thus, the two interventions came out presenting “not that easy”

<sup>1</sup> Structure from Motion/Multi-View Stereo

<sup>2</sup> Şevketoğlu [2017:185] mentions the difficulty of documenting the graffiti while the balcony and its narrow space causes an obstacle for the overall view and documentation of the ship graffiti.

situations to manage. For the ship the main issue was linked to the very dark (and somewhere shining) colour of the wood (the processing of the data from this survey is now ongoing during this writing and will be presented on a next occasion). The graffiti were presenting a quite articulated set of difficulties in operating photogrammetry; these various troubles should be described as follows:

1. It was a sort of “not expected” intervention, so the tools brought to Kyrenia were not that specific for such a survey, thus the presence of a high-resolution camera equipped with a macro-photography lens, a Micro Nikkor 60 mm F2.8 [Verdiani et al. 2018], turned out as a proper solution in giving a chance to this survey.
2. Proper lighting was missing, the very low, diffuse lighting, not optimized for presenting the graffiti, was a potential problem, forcing into long time exposures, into setting up high ISO values, into stopping down the diaphragm of the lens to wide open, or using a mix of the three above mentioned conditions that are generally well known for reducing the quality of the following results of the photogrammetric processing.
3. The floor of the gallery was quite unstable, or, better, it was enough stable for walking and visiting without feeling literally “on a ship”, but was not stable enough to avoid movements of the tripod and shaking of the camera when other people were passing by during the visiting time.
4. The U-shaped gallery, passing in front the graffiti is a narrow space, large about 120 centimeters and just in front of a quite high element, a plaster area of variable height presenting graffiti up to three metres from the floor of the gallery. Such a condition causes difficulties for the shooting, forcing the photographer to stay quite close to the lower part and quite distant from the top part, with the result of having a very different effective size of the pixels in the close up and far shots.
5. People keep visiting the area during the shooting: for some reason it was not possible to obtain a stop in the visits for the time needed to take all the pictures, thus it is worth to say that being an “out of program” activity in front of the main survey of the castle, it was difficult to setup the operation for a proper management of the visitors access.

## FROM TROUBLES TO CHALLENGES

The premises to this photogrammetric work were not that nice, the many difficulties should drive the idea of a too high level of possibility about losing time and producing only poor results. To go beyond this concerning and get positive about the possibilities, a series of countermeasures were taken. The main set of them can be described as follow:

1. The first one should be defined as just “philosophical”, instead than mumbling about the “not expected” as an issue, the approach was changed moving the situation from a trouble hampering the operations into a challenge, thinking about all the opportunity of success and considering the positive aspects of the tools and skills available.
2. To obtain well usable images the sensor of the camera was setup with medium ISO values (from 320 to 640), exploiting the low noise of the full frame (FX) sensor. The camera in use was a Nikon D800e, (the model with the same sensor of the D800 basic, but with no antialiasing filtering, a technical solution made to enhance the sharpness of the resulting images. The variable setting of the sensor was modified to allow long exposure times limited to two to four seconds speeds, using at the same time a remote trigger and the self-timer setup with 2 seconds of delay, in this way any accidental vibrations caused by the pressure of the shooting button was resolved. Obviously ~~then~~ it was a matter about staying motionless nearby the camera if the exposure time. All the pictures were taken directly in RAW and JPG format, exploiting the option from the camera about saving automatically both formats. Later, in the photogrammetric processing, at first model was developed using the JPG pictures only. The low but homogeneous light, with no need to correct shadow/light issues, the medium to low ISO speeds of the sensor and its minimal noise and finally the excellent quality of the JPG coming from this camera, allowed preferring this format so to speed up the following processing. The RAW format was kept behind for a following processing, yet to be done at the moment of this writing.
4. The lens in use, the Micro Nikkor 60 mm F2.8, is capable to focus at close range (33 cm minimal focus distance) [Erlewine 2011] for this it was possible to operate in the narrow space of the gallery in a more comfortable way, using a quite small tripod, quite light but with a good height, then stopping down from F2.8 to F8.0 accordingly to the positioning of the camera, opening the diaphragm (so to have faster shutting speeds and/or lower sensor ISO settings) when the sensor plane was parallel to the plaster (the scrapes of the graffiti are not deep enough to suffering of out-of-focus issues in this case) and closing when the plane of the sensor was tilted respect the plaster surface (to

allow having a larger “in focus” area with all its pixels fully usable for photogrammetry processing) [Hoddinott 2013]. In all the frontal shots the GSD was typical for close range photography, with a pixel size of about 0.003 cm. As long as it was possible, the shooting was operated moving the tripod and the camera parallel to the wall surface, with about 1/4 to 1/3 overlapping between consecutive frames in horizontal as well as in vertical, when there was no other way than tilting the position to complete the coverage, the overlapping was a little increased, obtaining a reasonable B/D ratio [Stanco et al. 2017] and then augmenting the possibility to find common features between frames.

5. The countermeasure to the stepping on the floor of the visitors was simply keeping a calm and relaxed approach to the situation in the gallery and waiting for the people visiting to pass by. So, in the end this was even useful to learn something more, gathering visitor’s opinions and noticing how much they pay attention to the presence of Graffiti on the walls. In most of the cases they were completely ignoring them, passing by and looking down to the relic neglecting the wall at their shoulders. When advised on looking back, supporting their viewing using the flashlight of their smartphones, the presence of the graffiti was immediately noticed by all of them, their reaction being between interest and surprise, rarely accompanied by questions (thus it is worth of saying that for many of them speaking in English was quite a problem), asking mostly about the age of the artwork and if such a decoration was ancient or not.

## POST-PROCESSING OF THE DATA

The following processing was quite a classic one, the set of about 160 pictures taken was checked and reduced to a sub-selection of 144 images, all the (few) shots with excessive shaking blur or focusing defects were removed [Guidi and Gonizzi 2014; Manganelli Del Fà et al. 2015]. . The photogrammetric processing was done using *Agisoft Photoscan*<sup>3</sup>, starting from the alignment process, the generation of a dense point cloud (of about 3.3 million points) followed by the polygonal mesh production (setting to zero the decimation and getting a surface of about 13.5 million faces). The photogrammetry model was put in scale using a set of points taken from the 3D laser scanner point cloud produced in the same workshop, the points were connected by a “ruler” then used to receive the same measure read from the point cloud, once applied the model was scaled correctly and aligned in the same coordinates of the 3D laser scanner survey. Then, the mesh was exported to *Raindrop Geomagic Studio*<sup>4</sup>, where the geometry was treated for polygon correction, holes capping, decimation (reducing it to 7,500,000 triangles), then imported back to *Agisoft Photoscan* for the generation of the texture on the optimized mesh (this was done producing the texture atlas divided into eight JPG images of 4000 px x 4000 px (=16 Mp).

The resulting textured model was then exported to *Autodesk 3D Studio Max*<sup>5</sup> for the final processing, the production of high-resolution images and of some short animations to show all the graffiti present on the plaster. In the rendering process the two main outputs, both the frontal views and the animations were organized exploiting the artificial lighting to put in evidence the graffiti work. Moving a classic digital “direct light” with parallel projection it was possible to enhance the readability of the graffiti traces. In the animations these lights were moved and turned around the model to allow a better perception of all the details present in the graffiti work. Considering the possible difficulty from some user to recognize all the elements at first and to keep high the attention on the video, during the video-editing phase, for each single graffiti, a retracing of all the main carved line was placed in overlay to each boat/ship. This made it easier to display the contents, evidencing elements and details otherwise difficult to read. The retracing was made manually using a vector drawing software, *Corel Coreldraw! X6*<sup>6</sup>, operating on a single frame extracted from the animation and then reinserted with a longer duration to allow a “stop” effect with the gradual appearance of the lines of the tracing. The lines were evidenced giving them a light orange colour, well balanced in front of the background and capable to attract attention and leave a certain “persistence of vision” to the observer [Oxon 1899]. The retraced lines were then exported in TIFF format to preserve the transparency of the background and make easier to align/manage them in the video-editing software *Adobe Premiere CS6*<sup>7</sup>. The video, complete with notes about the “making of” for this digital 3D model and animation is accessible in YouTube at a direct link<sup>8</sup>

<sup>3</sup> [www.agisoft.com](http://www.agisoft.com)

<sup>4</sup> [www.3dsystems.com](http://www.3dsystems.com)

<sup>5</sup> [www.autodesk.com/products/3ds-max/overview](http://www.autodesk.com/products/3ds-max/overview)

<sup>6</sup> [www.coreldraw.com](http://www.coreldraw.com)

<sup>7</sup> [www.adobe.com/products/premiere.html](http://www.adobe.com/products/premiere.html)

<sup>8</sup> <https://youtu.be/Yqw1ZrdWH1A>

It is probably the best way to appreciate these graffiti if not visiting directly the Kyrenia Shipwreck Museum in Kyrenia, Cyprus Island, thus, right now, for any visitor arriving there, it is better to have a small flashlight ready to help the reading with the present state of the exhibition.

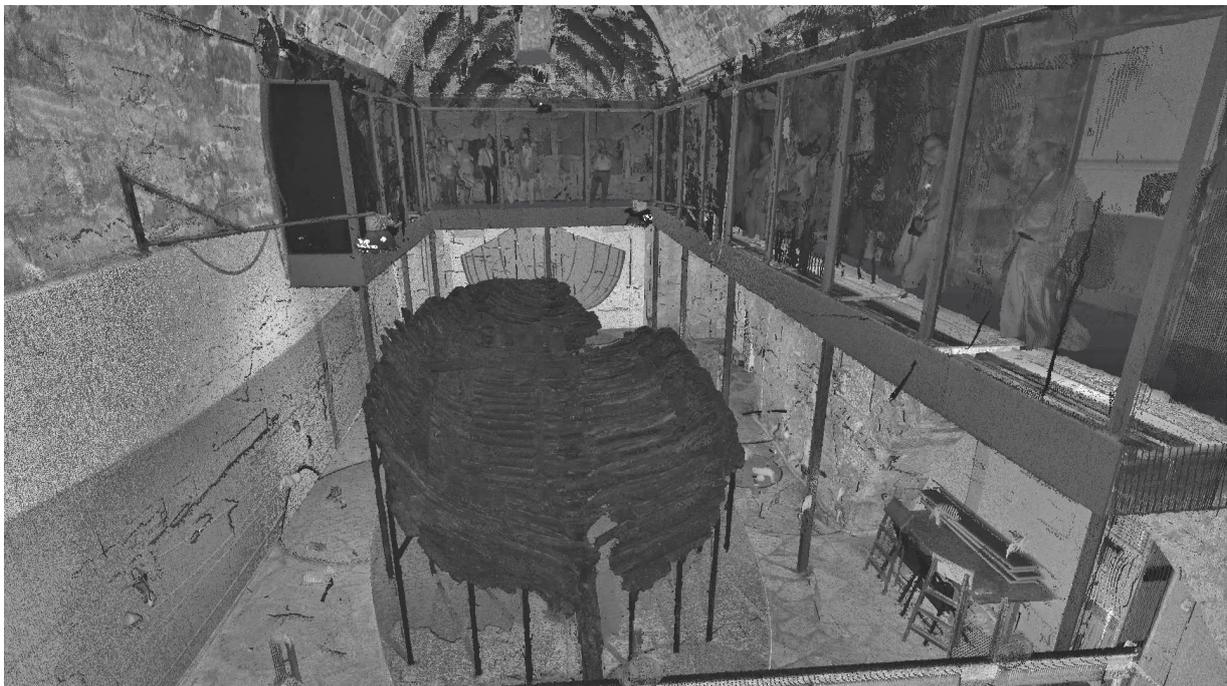
## CONCLUSIONS

At the moment of the writing the production of a high-resolution image of the whole plaster element is ongoing and almost completed. Its main use will be to display the whole set of graffiti from this part to people interested in the subject, with nice potential opportunities for teaching and learning about this specific artwork. This rendering should be used to build up a panel version of the graffiti interpretation and description (for exhibition on-site and/or online viewing and downloading).

Hopefully, in the future it can be foreseen the possibility to go back to the Kyrenia Castle for completing the survey of other parts, that time with some more dedicated tools like a higher resolution camera (about 50 Mp sensor) with wireless remote control and equipped with a more versatile tripod with sliding head and column (so to allow the reaching of difficult points with ease), portable flash lighting system, with soft diffused light, compliant with the preservation of the artwork and excellent in giving faster shutting speeds and possibility of extended depth of field while fastening all the operation by the possibility of operating with the camera handheld for many positions.

At the same time some extra processing can be completed soon on the actual model to allow the production of some 3D printing tests, presenting a partial 1:1, an enlarged detail from some significant part and a reduced version of the whole plaster element. It should be a possible idea to try a complete 3D reconstruction of the represented fleet, maybe something to think about for some future day, aimed to the production of a multimedia presentation oriented to teaching the whole story from these traces belonging to an exciting past.

## FIGURES



*Fig. 1. View from the 3D Laser Scanner point cloud of the Kyrenia Shipwreck and its aerial gallery*



Fig. 2. Sample shots from the photogrammetry campaign, on the top the full shot, beneath it the enlargement of a detail from each shot to allow the reading of the quality of the resulting image

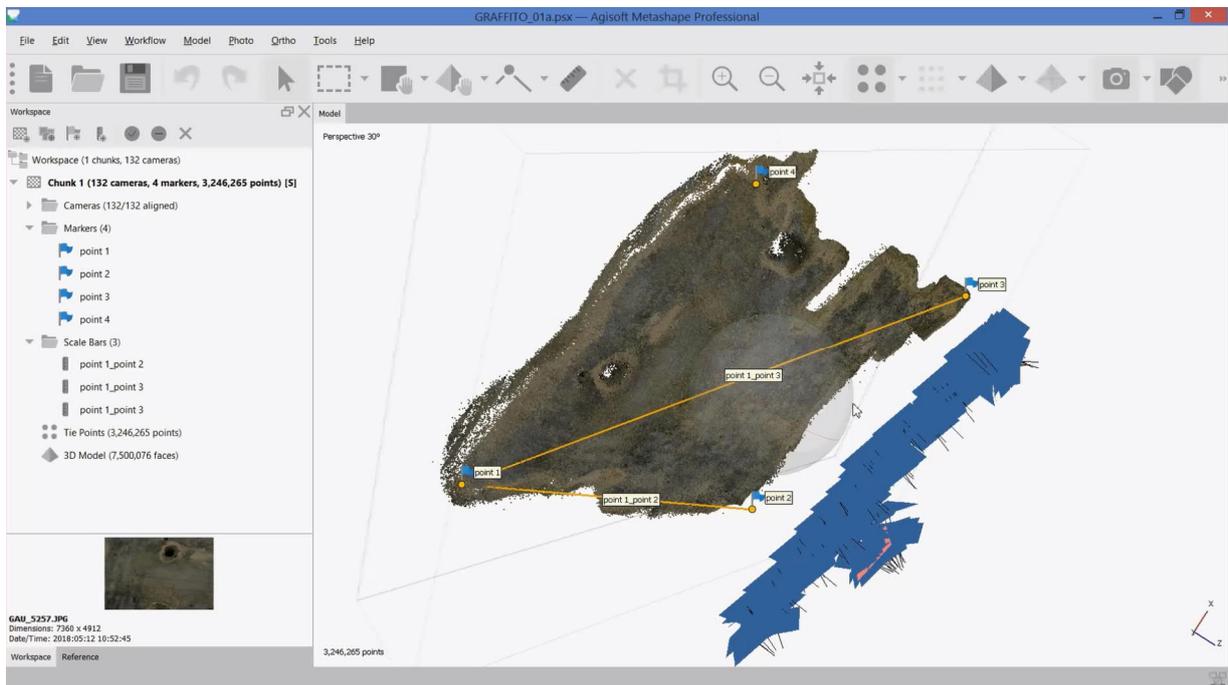
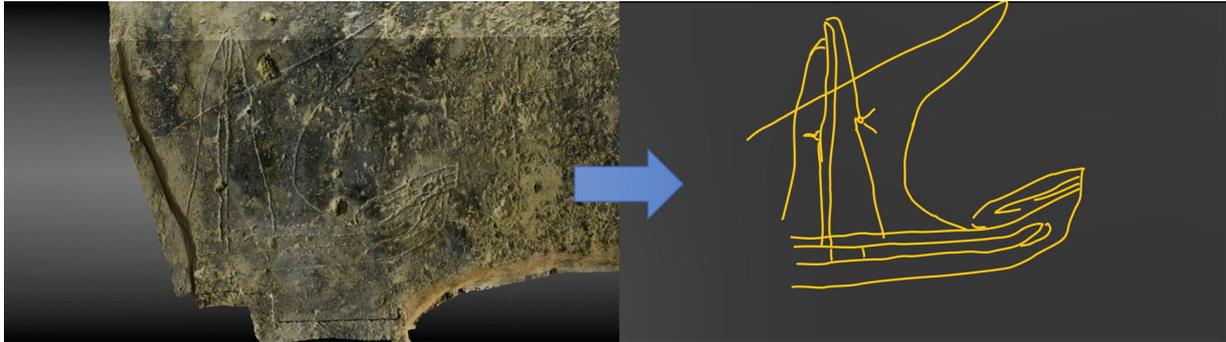
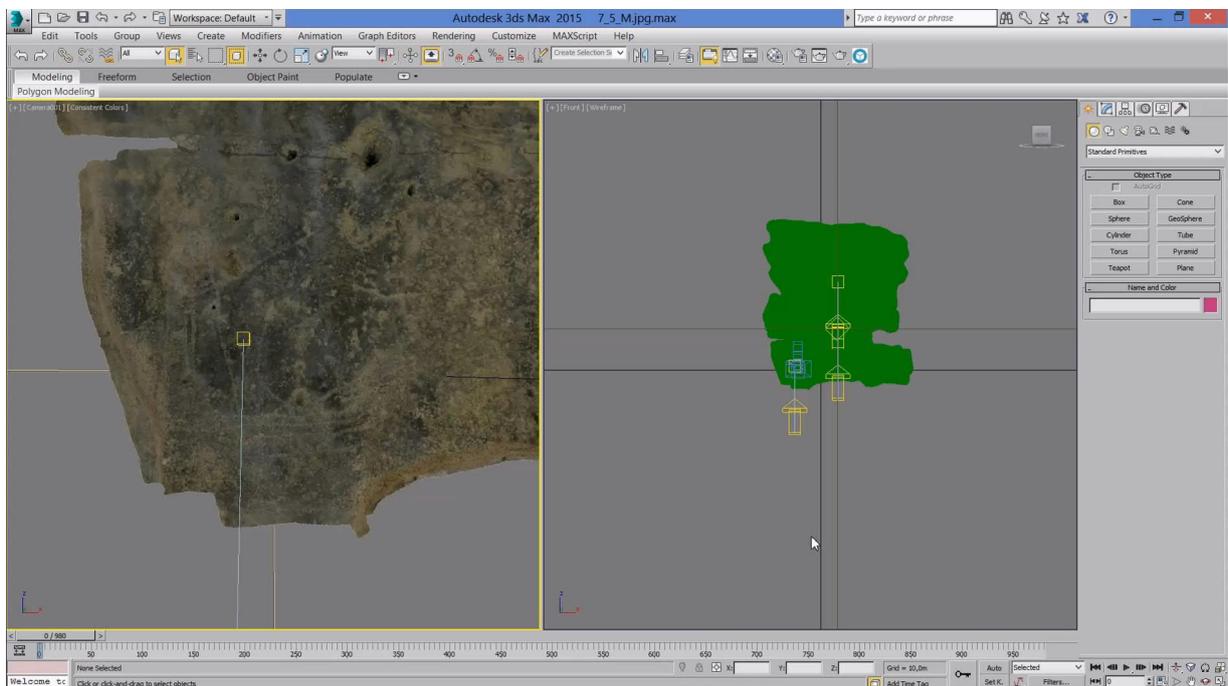


Fig. 3. Processing in Agisoft Photoscan, point cloud and the putting in scale of the model



*Fig. 4. The retracing of the graffiti into vector drawings*



*Fig. 5. Preparation of the animation with light motion in Autodesk 3D Studio Max*

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