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.

Key words:
SfM, 3D documentation, Kyrenia Castle, medieval fragment.

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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 synthetized 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 aseptic object that predict its rotation to acquire all its sides, including the bottom.

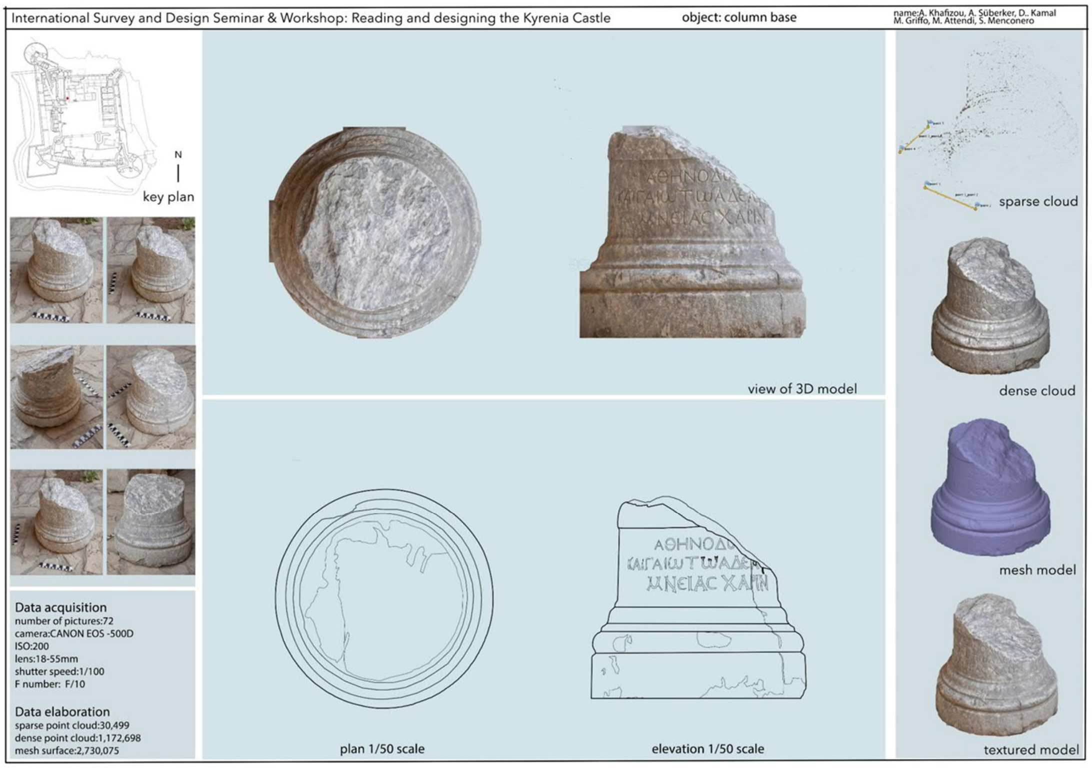

Fig. 3. Data capture and elaboration: from Structure from Motion to 2D representation

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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