3D DIGITIZATION OF TRANSLUCID MATERIALS IN CULTURAL HERITAGE OBJECTS: A COMPARATIVE STUDY BETWEEN LASER SCANNING AND PHOTOGRAMMETRY

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Abstract. This paper presents a detailed comparative study between the two main methods of 3D digitization, photogrammetry and 3D laser scanning, regarding their performances with known difficult materials. For this study were selected two objects that were sculpted in two specific translucid materials: jade and candle wax. These types of materials are particularly hard to scan due to their special properties at the light interaction with the surface: subsurface light scattering and strong specular reflections. The paper details both data acquisition and 3D reconstruction process and discusses the results, emphasizing the advantages and disadvantages of both methods regarding the 3D digitization of this class of materials.

Key words: subsurface light scattering, specular reflection, cross-polarization.

1. INTRODUCTION

A recurring theme in the research and application of non-contact 3D digitization methods for physical surfaces is the difficulty that certain classes of materials are posing for an accurate geometrical reconstruction. Usually this difficulty is caused by the material properties at the interaction with the electromagnetic radiation used for data acquisition. Non-contact (or optical) data acquisition techniques used in 3D digitization are based on the capturing the reflected radiation (either if it's active of passive) from an object's surface in order to calculate three-dimensional coordinates of the real points of the surface. In this paper we will be focused on a comparative study between photogrammetry and 3D laser scanning applied on two types of 'difficult' materials: jade and wax.

It is known that the visibility of a physical surface is given by the observer's capacity to detect the reflected (or emitted) electromagnetic radiation by that surface. Because the human eye detection range is limited to 400–700 nm, it will not be able see a surface that is not illuminated with a radiation within that range. Same thing goes with the digitization devices' detectors. But the most important thing of this aspect in our study is the fact that surfaces react different to different radiation. There are several phenomena that defines the interaction of radiation with matter. These phenomena are determined by both radiation and matter properties and allow us to easily classify materials and surfaces by their reflected color or the geometrical configuration of the radiation. Of these phenomena we are most interested in the ones were the propagation direction of the radiation is changed upon the contact with a surface: reflection, refraction and diffusion.

1.1. LIGHT TRANSPORT MODELS

One way to characterize the behavior of light at the interface between two different media is to use mathematical models of transport. These models were first developed in the field of Computer Graphics for the simulation of digital photorealistic representations of these light-matter interaction phenomena [1]. This paper will not discuss the details of these models but will make use of references that will contribute for a better understanding of the reason why some materials are difficult to digitize by optical means.

Light radiation is emitted from a source in a medium and it propagates until the interface with another medium with different properties. At the point of incidence several cases may occur (see Fig. 1) depending on the second medium properties regarding the incident radiation. A simplified view of this entire process can be resumed in the following taxonomy: transparent, translucid or opaque bodies. The focus of this paper will be on translucid and specular reflection bodies.

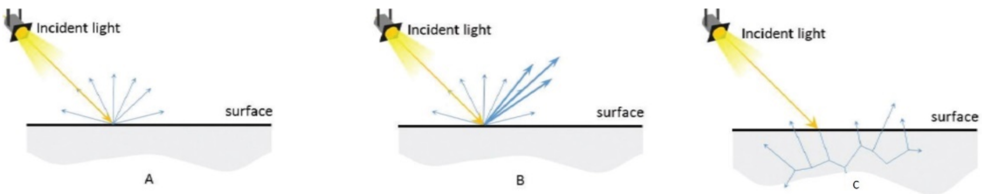

Fig. 1 – (Color Online) Light transport models (adapted from [2]).

One of the models that are characterize the objects within this study, is *sub-surface light scattering (translucid bodies)*. When light interacts with a translucid body, it propagates through the object material, is scattered, and then it comes out through the incidence surface or it continues to propagate through the whole body (Fig. 1 C). The light propagated through the whole body comes out diffused and cannot define correctly the shape of the body. Translucidity is better observed from the opposite direction of the incident light. These types of surfaces, with direct illumination, due to the light scattering, loses its details when it is observed. For this reason, laser scanning systems have difficulties in correctly recording the 3D coordinates of the shape because the laser beam is not reflected back right from the surface. In this class of materials, we can name old glass, wax, marble, organic materials, special properties glass etc.

The second model of interest is *diffuse and specular reflection (shiny surfaces)*. When the incident radiation is reflected by the surface in multiple directions, we have diffuse reflection. Ideal or Lambertian diffusion is considered when the reflection has an equal luminance when observed from all possible angles (Fig. 1 A). The closest to this special situation the friendliest to scan is the surface. Things get complicated when specular reflection appear.

Shiny surfaces, depending on their geometry, have specular reflections on certain angles of observation (Fig. 1 C). These reflections are characterized, from the observation point, by a lack of detail and information, due to the light concentration. That's why the detector cannot capture shape or color. This is a problem for both 3D laser scanning and photogrammetry. In this class of materials, we can name metals, glazed surfaces, glass, marble etc.

The 3D digitization of objects containing surfaces with these classes of materials usually results in poor results. In industry fields these surfaces are usually treated with special materials like powder or spray, in order to correctly record the shape (but not the color). Another practice is to completely remove the problematic area from the 3D model and replace it with simulated, estimated or modelled mesh.

In Cultural Heritage these practices are not recommended for multiple reasons. The use of powder or spray to cover the problematic surface comes in direct contradiction with the preventive conservation practices [3]. These powders are based on chemicals that can affect the surface of the object. Once the scanning is completed these chemicals have to be removed either by washing, mechanical brushing or air blow [4]. The replacement methods can be taken in consideration only for presentation and exhibition purposes, but with no scientific or documentation value. In Cultural Heritage, a 3D digitization, like documentation photography, is an instance in time of the visual and structural conservation state of the subject. For this reason, this process should result in a digital copy of the surface, in the greatest detail, with no alterations.

1.2. 3D DIGITZATION METHODS AND THEIR LIMITS

Today there are three main methods of digitization that provide top quality results in most situations: 3D laser scanning, photogrammetry and structured light scanning. Each of them has its own advantages and disadvantages but they can complement each other when either of them can't provide the required results.

Both laser and structured light scanning technologies are based on time-of-flight or triangulation methods. These devices are usually built for specific purposes and come in a various range of models, each designed for different applications (object size and scan accuracy). Triangulation based devices project a line or a pattern of lines on the surface, while a detector position at a calibrated distance records the reflected signal in order to calculate the 3D coordinates and surface geometry. Both methods usually employ visible or near infrared light or laser beams. This is why these are active methods.

The surfaces with materials that absorb, specular reflect or transmit the wavelength of the active device laser or light beam or pattern of beams, are a serious problem for the 3D reconstruction. The detected (reflected) signal is either not strong enough, has a different apparent position in the depth of the surface or it doesn't even reach the detector anymore. All these issues lead to an incorrect geometry calculation.

Photogrammetry, on the other hand, is a passive method for imaging measurement and interpretation for the determination of the shape and position of an object from one or more photographs of that object [5]. At its core, photogrammetry uses the fundamental central projection model. Each photograph image generates a bundle of spatial beams, defined by the image points and the perspective center. If all the bundles from more images intersect, a dense web is created. Using the bundle adjustment method, a greater number of such bundles can be oriented, calculating this way the three-dimensional coordinates associated to the object points. Today's major automated digital photogrammetry processing algorithms are based on this method.

In order to apply these algorithms, the source images must contain the point we want to reconstruct in at least three different angles. This constraint results in a required partial overlapping of the source images.

Photogrammetric measurements can generate digital three-dimensional reconstructions of an object (coordinates and derived geometrical elements) or graphic shapes (images, surveys, maps).

The quality and precision of 3D digitization using photogrammetry is directly dependent on the source images quality (operator skills, camera sensor, light) and the initial goal of the measurement. Versatility of this method makes it suitable (with the same equipment) for any type of subjects [6] or even with different radiation sources for imaging, like X-rays [7].

1.3. OTHER STUDIES AND SOLUTIONS. STATE OF THE ART

As mentioned before the go-to solution in industry is the use of thin layers of a special powder or spray that cancel the problematic effects of the surface: transparency, specular reflections or subsurface scattering. The research of these special compounds is in continuous development, for the improvement of the scanning accuracy [8]. But for Cultural Heritage assets' surfaces this is not a viable solution.

There are many studies that tried different approaches to solve or reduce the effect of these materials during 3D digitization. One common theme is the use the selective optical properties of the materials (UV and IR radiation). Very good results have been obtained and confirmed for transparent objects using laser induced fluorescence scanning ([9] and [10]) in comparison with polarized IR radiation. Another successful approach was the immersion of a transparent object in a liquid that fluorescence when irradiated [11]. This way the surfaces appears dark and the triangulated points are actually the fluorescent response of the liquid around the object during the scan.

A comprehensive comparative study [12] in medical research used multispectral imaging photogrammetry for the digitization of teeth. Teeth are a combination of translucid and specular reflection glaze and mate areas. In this study was compared photogrammetry at different wavelengths (UV, UV fluorescence, UV reflectance, visible light) with tomography, micro-tomography, laser scanning and structured light scanning for a set of teeth. The conclusion of the study was that UV reflectance photogrammetry (at 365 nm) provided the best geometry reconstruction for both the glazed part and the bone part of the teeth. Added to this, the visible light photogrammetry resulted textured was used in order to have a complete high accuracy (90 µm error) realistic digital replica.

A different approach worth mentioning is RTI/H-RTI (highlight reflection transformation imaging). This is rather a new photometric method of creating a composite image from multiple images recorded from a fixed position but with illumination coming from different angles. Using a polynomial texture mapping algorithm [13] the normals to the surface can be calculated and further a 3D topography of the surface can be reconstructed [14]. Good results have been reported with translucid materials like ancient gems [15] or prehistoric obsidian artefacts [4].

In our usual practice, we are using complementary methods for the documentation of a cultural heritage asset. In this regard we have experience working with some materials in the discussed class (namely highly specular reflections type) like porcelain [16] or glazed terracotta [17] where we used a wide range of investigation methods for a thorough documentation, including photogrammetry.

2. MATERIALS AND METHODS

The purpose of these measurements was to evaluate the efficiency of both photogrammetry and laser scanning for the 3D digitization of typical Cultural Heritage objects that have in their structure materials known to be problematic for accurate geometrical reconstruction by optical means. Two objects were selected, two statuettes, with a complex surface and many hidden areas. Although both objects are sculpted in translucid materials (jade and candle wax), one of them has a mate surface while the other one has strong specular reflections.

The first subject is a female figurine sculpted in candle wax. Wax or candle wax is a Hydrocarb that has been studied for a long time [18] but especially after the 90s, a period when the home fires caused by candle wax increased massively [19]. Wax properties makes it the perfect medium for artists to model or to build molds. At room temperature it can be sculpted. It has a low melting temperature and can be easily mixed with dyes in order to change color or texture. In the 16th and 17th centuries it was common for the famous people to have wax effigies at their funeral ceremonies. Today you can also visit entire galleries of celebrities sculpted in great detail out of wax.

If not coated with paint or other compounds, wax behaves like a (semi) translucid material with a mate surface.

The object has the maximum overall sizes of 18.5 cm × 5.5 cm × 3 cm with some areas of less than 0.5 cm thickness.

The second subject is also a feminine figure, but sculpted in jade. This statuette presents detailed elements like face features, folded robe and a bouquet of flowers. The sculpture is positioned on a square base of 7.2 cm × 7.2 cm that along with its total height of 24.5 cm marks the whole spatial volume the statuette occupies.

2.1. EXPERIMENTAL SETUP

The 3D laser scanning was done with Next Engine 3D Scanner Ultra HD. This scanner uses the triangulation method by projecting several parallel laser lines on to the object surface. It can record color texture and has a synchronized rotating table for automated scanning on a vertical axis rotation of 360º. It can acquire data with 0.005 mm accuracy and a spatial resolution of 0.1 mm. Data processing is done with its own software. The whole workflow can be automated with minimum human operator intervention.

Photogrammetric method, on the other hand, requires manual data acquisition, image processing, data processing. So, it is expected to take a longer time from start to finish. We used a full-frame sensor camera Nikon D810 (36 megapixels), 60 mm lens with a circular polarizing filter. Uniform lighting was provided by two light sources (each with 5 × 45W white fluorescent light bulbs) modified with two large softboxes. Both lights were positioned at 45º to the optical axis of the camera for the best polarizing effect. Other accessories use were coded targets for scaling and image alignment, Lazy Susan table for object rotation, tripod and a uniform colored background.

In order to cut the specular reflections, we employed *the cross-polarization method*. Polarized filters are optical elements that allows only the light rays with vibrations on a certain direction [20]. A secondary effect, usually sought by photographers, but that must be taken into account for correct color texture of the artefacts, is the color saturation added to the image and the increased color dynamic range [21]. These effects usually improve the quality of the image. Light polarization is often used in photogrammetry for the digitization of museum artefacts with great results for marble and bronze materials [22].

Cross-polarization method further reduces the high specular reflections by adding another linear polarizing filter to the light sources. So, the incident light on the shiny surface is already linearly polarized then reflected to the camera that has a circular polarizing filter, thus cancelling much of the specular reflections. It does not completely remove the highlights but in most cases, it massively reduces them. This method was thoroughly documented in several medical applications [23].

With these measurements we intended to compare the photo-realistic quality of the textures and the accuracy of the 3D geometric reconstructions obtained with both methods. Other evaluated criteria were: full process duration (data acquisition and processing), hidden are reconstruction capacity and the possibility of workflow optimization of both data acquisition and data processing for overall quality improvement.

2.2. DATA ACQUISITION

For 3D laser scanning, both objects were measured in identical conditions. They were placed, each, on the rotation table with a working distance of 64.6 cm. The system performed a 360º (rotation on vertical axis) full scan. The final scan for an object consisted in 16 partial scans that took 1 hour and 50 minutes.

Fig. 2 – (Color Online) Laser scanning procedure for the two subjects.

In the images above are the two objects during the laser scanning procedure. To the left is the jade statuette, while in the middle and to the right is the candle wax statuette. The last two images portray the effect of subsurface scattering with diffused light reemergence from the body of the object during the laser scan and flash light texture recording.

The images for the photogrammetric processing were recording following a good practice method [24] and all the recording parameters were set prioritizing the depth clarity of the images and detail quality. For this purpose, was measured the largest width the objects would have during data acquisition with the camera changing the optical axis angle. Using this value and the working distance to the object it was determined the best aperture that would ensure a large enough depth of field so that at any angle the subject would be in focus. Using the circular polarizing filter and a closed aperture greatly reduces the amount of light that reaches the camera sensor. In order to make sure that all the surface details have a good visibility the ISO sensitivity was increased to 800 while the exposure time was set to 1/6 s.

For the jade statuette were recorded 95 images at different heights while rotating the object with the Lazy Susan table. The recording took 10 minutes (without the workplace setup). For the wax statuette were recorded 161 images, in a similar fashion, taking about 30 minutes.

2.3. DATA PROCESSING

Laser scanning processing is realized using the same software used for data acquisition. It basically stitches the 16 scans in order to generate a complete 3D reconstruction of the whole object. Usually the workflow is quite straight forward with no need of intervention. The whole processing for the jade statuette took 2 hours. In the case of the candle wax statuette the automatic stitching was not successful so it required unique markers for each of the scans that had to be aligned. These markers are chosen by the operator and are usually visible features.

Photogrammetry processing is consisted of several steps, all dependent on the skills of the operator. First step is optional but recommended: image preparation. Using image batch processing programs (for fast improvement of all the images in the set) the operator performs the following operations: lens profile adjustment, color and white balance corrections, overall image quality improvement (shadows, highlights attenuation).

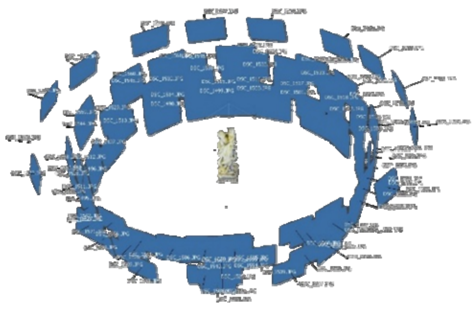

Fig. 3 – (Color Online) Jade statuette image alignment and estimated camera positions.

For the 3D reconstruction we used AgisoftMetashape Pro 1.6.2. The whole reconstruction process had two main steps: image alignment (Fig. 3) and mesh generation (from depth maps). In both cases we used similar settings: 80.000 tie points, 6.000 key points for image alignment. Coded targets were automatically detected and used as scale bars and also helped with the alignment. Several images were masked for general background removal. For the jade statuette the processing took 4 hours while for the candle wax statuette it took 50 minutes.

3. RESULTS AND DISCUSSION

For the jade statuette the laser scanning method generated an optimized 1.79 million polygons mesh. Photogrammetry generated a mesh with 6.15 million polygons. For volumetric and morphological comparisons, the photogrammetry model was simplified to the number of polygons of the laser scan model. In a similar fashion, the photogrammetry reconstruction of the wax model generated 16 million polygons that were simplified to the much smaller count of polygons generated with laser scan: 800.000 polygons. Both methods generated color textures for both of the objects.

Fig. 4 – (Color Online) Visual comparison of the jade statuette generated 3D models: A, C – photogrammetry, B, D – laser scan.

Upon visual examination of the jade statuette 3D models resulted, it is quite clear that both reconstructions preserved all the surface details and the main object features. Laser scanning reconstruction (Figure 4 B) appears to have missing parts at some curved extremities. Photogrammetry model presents some roughness where a smooth surface should have been. Regarding the photorealistic texture, with photogrammetry (Fig. 4 A) it was generated without issues and even complemented visually the mesh surface. Laser scanning color texture suffered from the specular reflections and generated many defects and visual artefacts (Fig. 4 D).

The images in Fig. 5 presents a detailed visual comparison of the wax statuette 3D models. Both models are much better, but still the laser scan generated model lacks small areas and presents small roughness compared to the photogrammetry model. The photogrammetry model was generated with no flaws. The texture of the laser scan model is much better compared with the jade statuette texture, but has lower quality than photogrammetry generated texture.

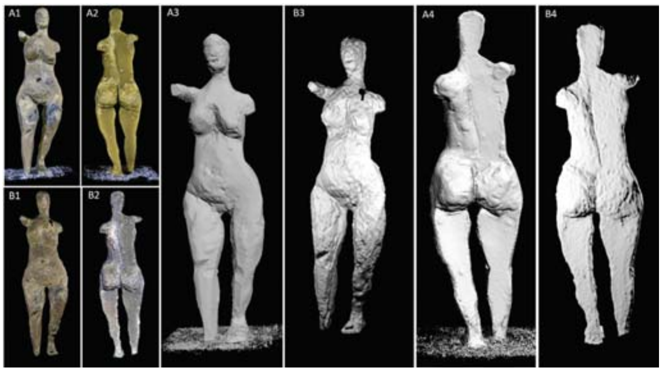

Fig. 5 – (Color Online) Visual comparison of the wax statuette generated 3D models:
A1-4 – photogrammetry; B1-4 – laser scan.

For a better comparison we analyzed the models in CloudCompare where we applied an absolute difference between the results of both methods for each subject. The difference was realized using the photogrammetric models as references. In Fig. 6, to the left, is a jade statuette detail showing with color codes the areas where the laser scan model lacked in 3D reconstruction. The red color represents differences up to 4 mm. It is quite clear that the laser scanning method had great difficulties with the reconstruction of thin edged areas like folds and corners, areas characterized by lower optical density (and thinner material), due to the fact that the laser beams penetrated the translucid material and almost no data was collected back.

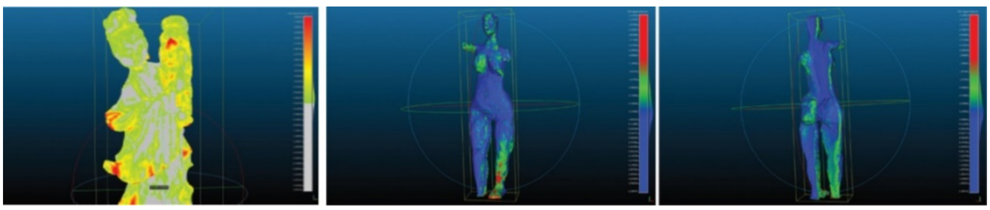

Fig. 6 – (Color Online) Calculated differences between the laser scan
and photogrammetry 3D models for each object.

Same method was used for the wax models (Fig. 6 middle and right). Here the differences are marked with green and red. Green color represents variations of 0.5 and 1.5 mm of difference while the red color marks differences up to 3 mm. Again, the greatest differences are on extremities.

4. CONCLUSION

In this paper we presented a comparison of two 3D digitization approaches – photogrammetry and 3D laser scanning – for the digital reconstruction of two artistic figurines, sculpted in so called difficult materials for 3D digitization: jade and wax. The properties of these materials, regarding their interaction with light sources, puts them in the class of translucid objects while one of them also presents strong specular reflections.

While the 3D laser scanning method was straight forward, from data acquisition to processing and final model, photogrammetry allowed for a more flexible approach. The liberty of light arrangement in combination with cross polarization method for the image acquisition, resulted in better data recording without specular reflections or strong subsurface scattering effects. Image post-processing also improved the source data. These led to a detailed digital reconstruction of both statuettes.

Laser scanning is a faster and an accurate automated process that does not allow for many tweaks or major method adjustments. In both experiments, the intensity of the laser beam and the light source for texture recording resulted in large geometry errors for thin areas of the subjects. Texture rendering was also problematic especially for the specular reflective subject, where a lot of erroneous artifacts were generated. The overall quality of both subjects was below the photogrammetric reconstruction.

The problem of difficult materials for 3D digitization is not new but also not thoroughly solved. It is a research topic that still has to provide better and more efficient solutions. If in the mechanical or medical industry these classes of materials can be successfully digitized with efficient powders, for the 3D documentation of Cultural Heritage assets this is most of the times not a solution. As a general rule it is recommended to know the limits of your available instruments in order to make a fast and efficient decision regarding the digitization process at the start of a new project.

With these experiments we wanted to see to what extent the two methods differ and whether any of them is suitable for the 3D documentation of objects with translucid materials or with specular reflections. Our results clearly pointed out that photogrammetry is more versatile, affordable and more efficient when dealing with these types of materials.

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REFERENCES

1. H. Jensen, S. R. Marschner, M. Levoy, P. Hanrahan, A practical model for subsurface light transport, Proceedings of the 28th annual conference on Computer graphics and interactive techniques (SIGGRAPH2001), Association for Computing Machinery, New York, NY, USA, 511–518 (2001).
2. R. Fleming, H. Jensen, H. Bülthoff, Perceiving translucent materials, Journal of Vision. **4**, 127–134 (2004).

3. ICOM-CC, Terminology to characterize the conservation of tangible cultural heritage, 15th Triennial Conference, New Delhi, 22–26 September 2008.
4. S. Porter, K. Missal, L. Pawlowicz, A Comparison of Methods for Creating 3D Models of Obsidian Artifacts, Computer Applications and Quantitative Methods in Archaeology (CAA), Oslo, Norway, 2016.
5. T. Luhmann, S. Robson, S. Kyle, J. Boehm, Close-Range Photogrammetry and 3D Imaging, Berlin, Boston: De Gruyter, 2014.
6. L. M. Angheluta, 3D reconstruction of archaeological artefacts from 2-D X-ray images, Optoelectronics and Advanced Materials – Rapid Communications **12** (11–12), 705–712 (2018).
7. L. M. Angheluta, R. Radvan, 3D digitization of an antique decorative textile artifact using photogrammetry, Romanian Reports in Physics **69** (3), 801 (2017).
8. J. Pereira, I. Silva Penz, F. Pinto da Silva, Effects of different coating materials on three-dimensional optical scanning accuracy, Advances in Mechanical Engineering **11** (4), 1–6 (2019).
9. R. Rantoson, C. Stolz, D. Fofi, F. Meriaudeau, Optimization of Transparent Objects Digitization from Visible Fluorescence UV-induced, Optical Engineering **51** (3), 033601 (2012).
10. F. Meriaudeau, R. Rantoson, K. M. Adal, D. Fofi, C. Stolz, Non-conventional imaging systems for 3D digitization of transparent objects: Shape from polarization in the IR and shape from visible fluorescence induced UV, AIP Conference Proceedings **1537**, 34 (2013).
11. M. Hullin, M. Fuchs, I. Ihrke, H.-P. Seidel, H. Lensch, Fluorescent Immersion Range Scanning. Turk, Greg: Proceedings of ACM SIGGRAPH 2008, ACM, Art. 87, 1–10 (2008).
12. A. Mathys, P. Semal, J. Brecko, D. Van den Spiegel, Improving 3D photogrammetry models through spectral imaging: Tooth enamel as a case study, PLoS ONE **14** (8): e0220949 (2019).
13. T. Malzbender, D. Gelb, H. Wolters, Polynomial texture maps, SIGGRAPH '01: Proceedings of the 28th annual conference on Computer graphics and interactive techniques, August 2001, 519–528 (2001).
14. M. Elfarargy, A. Rizq, M. Rashwan, 3D Surface Reconstruction Using Polynomial Texture Mapping, Bebis G. et al. (eds) Advances in Visual Computing. ISVC 2013. Lecture Notes in Computer Science, **8033**. Springer, Berlin, Heidelberg, 353–362 (2013).
15. D. Anghel, N. Har, C. Șuteu, M. Ursu, Metode de investigare mineralogice și petrografice ale unor intalii din colecția Muzeului Național al Unirii din Alba Iulia, Terra Sebus. Acta. Musei. Sabesiensis **8**, 83–104 (2016).
16. H. Sadek, M. Simileanu, R. Radvan, R. Goumaa, Identification of porcelain pigments by Laser Induced Breakdown Spectroscopy, Journal of Optoelectronics and Advanced Materials **14**, Iss. 9–10, 858–862 (2012).
17. Tirado-Hernández, J. Becerra, R. Ortiz, P. Ortiz, A. Gomez-Moron, L. Ghervase, I.M. Cortea, L. Angheluță, R. Rădvan, Non-destructive techniques applied to the study and diagnosis of ceramic and glazed terracotta works in Omnium Sanctorum church (Seville, Spain), in Science and Digital Technology for Cultural Heritage – Interdisciplinary Approach to Diagnosis, Vulnerability, Risk Assessment and Graphic Information Models, edited by P. Ortiz Calderon, F. Pinto Puerto, P. Verhagen, A. J. Prieto, CRC Press, London (2020).
18. M. Faraday, Faraday's Chemical History of a Candle, Chicago Review Press, Chicago, IL (1988).
19. A. Hamins, M. Bundy, S. E. Dillon, Characterization of Candle Flames, Journal of Fire Protection Engineering **15** (4), 265–285 (2005).
20. M. Novac, Fotografia de la A la Z, EdituraTehnică, București (1973).
21. J. Hedgecoe, The Photographer's Handbook, Third Edition, Knopf (2005).
22. C. Nicolae, E. Nocerino, F. Menna, F. Remondino, Photogrammetry Applied to Problematic Artefacts, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. **XL–5**, 451–456 (2014).
23. K. L. Hanlon, Cross-polarised and parallel-polarised light: Viewing and photography for examination and documentation of biological materials in medicine and forensics, Journal of Visual Communication in Medicine, **41** (1), 3–8 (2018).
24. L. M. Angheluță, R. Rădvan, Macro photogrammetry for the damage assessment of artwork painted surfaces, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. **XLII–2/W15**, 101–107 (2019).