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3D DIGITIZATION STRATEGIES FOR QUALITY ASSURANCE IN THE PRESERVATION AND DISSEMINATION OF ANATOMICAL ARTIFACTS

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Abstract

Universities have become repositories for preserving and exhibiting artificial anatomical artifacts, which were crucial in the scientific advancement of the 18th and 19th centuries. Over time, these artifacts fell into disuse due to new pedagogical methods. Today, there are challenges for their conservation and exhibition, although new ways of displaying collections are being explored. 3D digital technologies are promising but require constant review to ensure quality and accuracy in heritage documentation. This research examines the 3D digitization of artificial human, animal, and plant anatomical elements using photogrammetry and structured light scanning. It focuses on achieving an accurate volumetric record of high-resolution and faithful color textures to ensure the best preservation and dissemination. The findings highlight new image-processing strategies in photogrammetry, including procedures for dealing with out-of-focus areas before the processing phase. The design and 3D printing of targets, which improve the registration of volumes during scanning, are also discussed. The anatomical models obtained show solutions to common challenges in digitizing complex artifacts. This methodology, although specific to certain artifacts, can be adapted to any cultural object.

***Keywords**: 3D Digitization; Photogrammetry; Structured Light Scanning; Anatomical Collections; Quality in the conservation; University museums*

Introduction

Curiosity about the inner workings of the human body has been a recurring theme throughout history. In prehistoric times, individuals' ingenuity was tested by their available materials and technological resources. The exploration and teaching through empirical methods of natural sciences, including biology, has been traced back to Ancient Greece. Observing nature and engaging in hands-on practices with living or deceased organisms became the central pedagogical approach for training surgeons, veterinarians, and botanists. These practices held value not only in educating specialists but also proved to be a precious resource for artists striving to deepen their understanding of anatomy to enhance their creative works.

Innovative methodologies aimed at creating anatomical replicas for educational purposes led to the development of various three-dimensional teaching tools. Towards the end of the 17th century, surgeons, scientists, artists, craftsmen, and manufacturers conducted experiments with different materials, resulting in the emergence of the first three-dimensional polychrome wax models. The level of realism achieved with wax was truly astonishing. In the subsequent century, the distinctive quality of the material found applications in other fields of knowledge, such as

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veterinary medicine and botany. Their main objective was to craft artificial models that convey the highest degree of realism while ensuring their durability during their educational functions. Consequently, numerous experiments conducted during the 19th century led to the creation of other artifacts using materials such as paper-mâché, wood, gelatin, and plaster, among others. These artifacts made possible a detailed visualization of anatomical structures, ranging from the simplest to the most complex.

Many of these models proved to be remarkably captivating for their era. Their classical and tangible potential, often presented in various scales, greatly enriched the realms of human and animal anatomy. In botany, diverse magnifications allowed for the detailed observation of models from any angle, akin to examining them under a magnifying glass. These characteristics ignited immense enthusiasm among students and practitioners alike, fostering more effective study practices. Nonetheless, as teaching methodologies underwent significant changes during the 20th century, these educational tools were gradually forgotten. This paved the way for new forms of cultural heritage appreciation and preservation.

Recently, the aforementioned collections have garnered significant attention across fields of research due to their exceptional scientific and material attributes. As "material culture," researchers continue to emphasize the significance of the earlier scientific methodologies. Consequently, they have fostered a heightened interest in their preservation and safeguarding [1-6]. Their collective efforts are driven by the overarching goal of facilitating the transmission of knowledge among practitioners. In turn, future generations will be able to revisit and comprehend the historical and cultural contexts surrounding pivotal scientific discoveries.

Currently, three-dimensional anatomical collections are housed in numerous museums, universities, and higher education institutions worldwide. Despite the considerable efforts exerted by these institutions in preserving and sharing these collections, these tasks have become increasingly challenging due to limited material, human, and financial resources. Over the past decade, specialists have explored new methods for documenting and disseminating objects in more comprehensive and visually engaging ways. As a result, 3D models emerged as a promising and enriching tool for documenting, preserving, and analyzing cultural heritage [7-12]. In that regard, extensive research has been conducted on multiple 3D scanning methodologies for interventions in conservation and restoration processes [13-17].

New technologies require frequent reviews about the potential and quality of 3D digitization. This research examines issues that negatively impact the quality of 3D models and their correct dissemination and proposes solutions to ensure the best quality and fidelity in obtaining virtual models of anatomical artifacts. Some of the models selected for this study belong to the Universidad Complutense in Madrid and were located in the Anatomical Museum "Javier Puerta" of the Faculty of Medicine and in the Complutense Veterinary Museum of the Faculty of Veterinary Medicine. Others were retrieved from the Universidad de Salamanca, specifically the botanical models of the Department of Botany and Plant Physiology of the Faculty of Pharmacy and the Faculty of Medicine.

Objectives

The main objective of this research is to safeguard and share didactic anatomical collections while upholding stringent quality standards in both mesh acquisition and color texture. The study employs photogrammetry to develop novel image processing strategies focusing on filtering out-of-focus or distorted areas before the processing phase. This approach attempts to achieve the highest fidelity and quality in anatomical representations. Additionally, 3D scanning is utilized to enhance volume capture, particularly for artifacts with intricate volumetric characteristics.

Problems of 3D digitization using photogrammetry

Photogrammetry currently enjoys prominence as a leading methodology for digitizing cultural heritage, primarily due to its outstanding attributes of efficiency, fidelity, quality, and cost-effectiveness. This technique enables the thorough reconstruction of various intrinsic characteristics, including the object's position, orientation, configuration, and dimensions. Moreover, it provides valuable metric and geometric properties. These multifaceted insights are derived from the meticulous utilization of numerous images, captured from diverse angles and viewpoints [18].

When compared to structured light scanning methods, photogrammetry exhibits several advantages. Foremost among these is its capability to finely control the color management of photographs, resulting in enhanced accuracy [19]. Additionally, photogrammetry offers the flexibility to capture models under various lighting conditions, achieved through the utilization of diverse light sources within controlled environments [20]. Another noteworthy feature is its potential to generate models based on spectral images [21]. Furthermore, when contrasted with scanning methodologies, photogrammetry excels in reproducing color textures.

This way, photogrammetry emerges as an innovative and versatile tool that relies on a set of passive sensors, eliminating the need for specialized equipment. This enables the acquisition of three-dimensional data from objects with remarkable accuracy and comprehensiveness, particularly in the context of cultural heritage. The quality of each model mainly depends on the camera used. The current market offers a wide array of camera models. That is why a meticulous evaluation of the multiple types of cameras available for 3D documentation is required.

Several key attributes of a camera warrant special attention, the sensor and lenses being of utmost significance. The sensor's size dictates the number of pixels and is directly correlated with image quality. A larger sensor equates to a higher pixel count, resulting in enhanced accuracy and fidelity when capturing both volumetric and chromatic textures of the model [22]. Conversely, the selection of lenses can exert a substantial influence on the level of detail, with certain lenses capable of capturing more delicate nuances compared to others [23]. It's worth noting that the use of zoom lenses has been associated with significant distortions [24], being the reason why its use is often discouraged, particularly within the field of photogrammetry [22].

Effective management of the depth of field (DOF) presents a significant challenge when capturing photographs, as its precise control can have a substantial impact on the accuracy of the resulting 3D model. This parameter becomes particularly crucial when digitizing small-scale objects, primarily with the use of macro lenses. Insufficient or excessive DOF levels can jeopardize image alignment, introduce additional noise in point clouds, or diminish texture quality by creating non-existent or blurred elements [25].

Numerous studies focus on medium- and small-format models predominantly employing macro lenses. Researchers have noted that higher (DOF) values tend to reduce discrepancies between models and real-world data [26, 27]. However, it's worth noting that excessively wide apertures can exacerbate image degradation, leading to variations in image sharpness based on the distance between the camera and the subject [28]. Therefore, to achieve an acceptable level of sharpness, ultimately enhancing quality, detail, and fidelity, it is advisable to carefully select average DOF values. Typically, a value of f/8 is considered the ideal choice [22].

Recently, researchers began utilizing focus stacking techniques to enhance the accuracy and detail of the resulting 3D models [29]. These factors, which can occasionally be impacted by the complexity of the object's volume, the materials used, and the strategies employed, do not consistently yield optimal results. Despite following the capture strategies and photogrammetric processing methods outlined in various manuals and scientific articles [30-33], some anatomical artifacts have not achieved the desired level of quality in their finishes. This can occasionally result in errors in color texture, as depicted in Fig. 1. Such errors are frequently encountered during the recording of various artifacts and artworks.

Photogrammetric methodologies offer valuable means for comprehensive documentation of a wide spectrum of objects. However, when dealing with objects that possess extremely bright, dark, uniformly colored, reflective, or very bright surfaces, they have shown certain limitations. Photogrammetric software is constrained by its limited capacity for comparative analysis between successive images, rendering it susceptible to significant error propagation. In the case of highly complex anatomical artifacts characterized by intricate volumetric features such as rachis, peduncles, pedicels, and flowers, coupled with uniform colors and a lack of texture, achieving acceptable results with photogrammetry becomes impossible (Fig. 2). Consequently, to attain the utmost quality in both volumetric and chromatic representation and ensure the effective dissemination of these collections, various data capture and processing strategies were explored, employing both photogrammetry and structured light scanning.

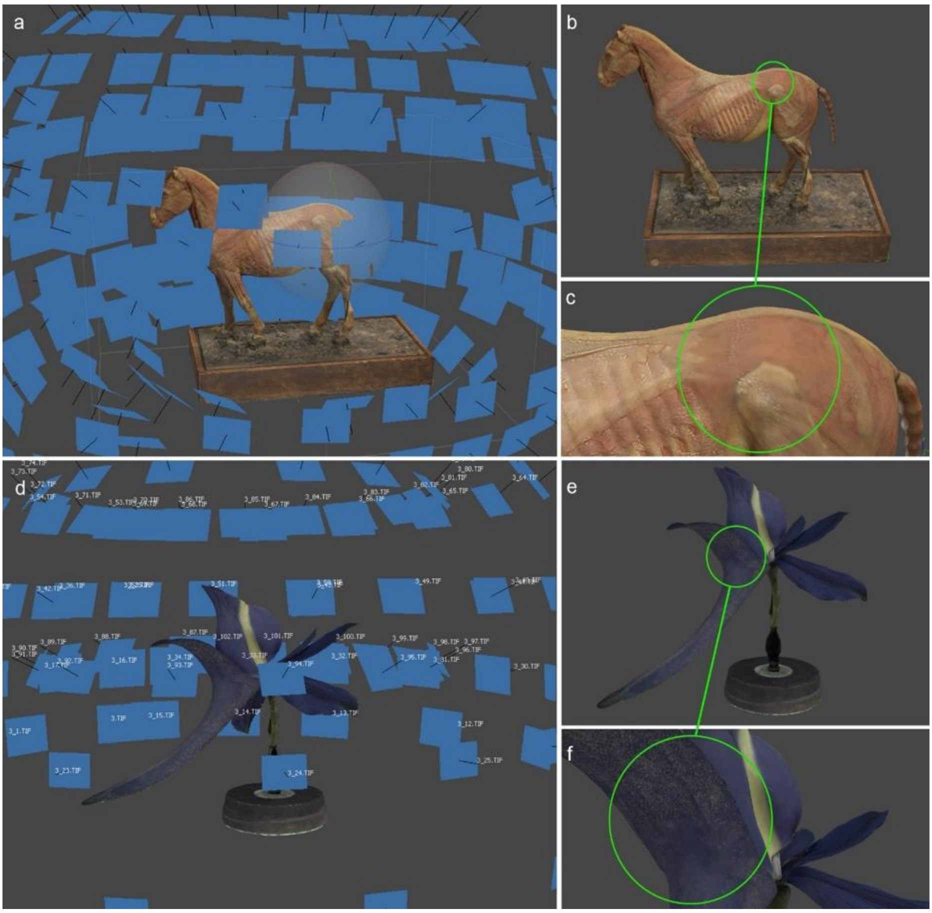

Fig. 1. a) Obtained photograph of the model "Caballo pequeño" attributed to Pedro Pablo Sánchez Osorio (n.d.) and Cristóbal Garrigó (1799-1863), taken in the XIX century for the Real Colegio de Veterinaria de Madrid. Ref.: MV-590 from the Complutense Veterinary Museum, Faculty of Veterinary Medicine of the Complutense University of Madrid; b) Blurred texture as a result of the superposition of photographs with out-of-focus areas; c) Detail of the blurred area as a result of the superposition of photographs with out-of-focus areas; d) Obtained from the photogrammetry of the "Delphinium consolida" R. Brendel model from the 20th century. Ref.: MAF-BRENDEL nº159/Ref.: UCM n.º 4012655 of the Collection of Clastic Models and Mural Plates for the Teaching of Botany of the Faculty of Pharmacy, Complutense University of Madrid; e) Blurred texture as a result of the superposition of photographs with out-of-focus areas; f) Detail of the blurred area as a result of the superposition of photographs with out-of-focus areas

Fig. 2. a) Model "Inflorescence in compound umbel" Les Fils d'Émile Deyrolle, 20th century. Ref.: MB-USAL-33 from the Botanical Model Collection of the Department of Botany and Plant Physiology of the Faculty of Pharmacy, University of Salamanca. b) Digitization by photogrammetry. c and d) Detail of the poor quality of the mesh obtained

Materials and Methods

3D digitizing by photogrammetry

Materials and capture configuration

The photographic documentation was conducted using a high-quality professional Canon EOS 5D Mark II, equipped with a 21.1-megapixel sensor and paired with a 50 mm fixed lens from the same manufacturer. To harness the camera's capabilities to the fullest, manual mode was selected, necessitating careful adjustment of various parameters. First and foremost, a RAW image format was chosen to ensure the preservation of uncompressed image data. Subsequently, the Adobe RGB color space was employed due to its capacity for richer color representation when compared to alternative models like the sRGB. Additionally, an average focal length of f/8.0 was selected to mitigate aberrations, distortions, diffractions, and the potential loss of sharpness typically associated with higher or lower values. The ISO setting was consistently maintained at the lower ISO 100 to minimize noise interference. Finally, meticulous attention was given to determining the precise exposure levels needed to enhance image quality.

It's crucial to emphasize that achieving superior quality and fidelity, encompassing both volumetric aspects and color texture of the model, relies on factors that extend beyond camera specifications and settings. Variables like lighting conditions, color management, and the digital processing workflow played a substantial role in shaping the final outcomes. Ambient lighting also played a pivotal role, and therefore, Nanlite FS-150 LED lights were employed to illuminate the analyzed artifacts. These specific light sources possess a color rendering index (CRI) of 95 and maintain a color temperature of 5600°K, among other attributes rendering them exceptionally well-suited for precise illumination of the objects. To ensure ideal light coverage, two light sources were strategically positioned at 45-degree angles relative to the object's orientation.

Lastly, the X-Rite ColorChecker card was incorporated into the capture environment to uphold color fidelity, recognizing its critical role in achieving outstanding figure rendering.

Positioned in proximity to the artifact, a single photograph was taken, which played a key role in generating camera profiles. These profiles are essential in guaranteeing the utmost fidelity in color rendering throughout the entire digitization process.

Capture strategies

In the context of the photogrammetric survey, a methodology centered on the utilization of a rotating platform within a controlled lighting environment, situated inside a lightbox akin to Neewer-type setups, was employed. The primary objective of this approach was to comprehensively capture the object by rotating it as needed. The consistency and precision of the illumination conditions played an essential role in ensuring optimal outcomes. Depending on the specific volumetric characteristics of each object under investigation, multiple positions were employed to facilitate complete documentation of the model. In certain instances, this required repositioning the object two or even three times (Fig. 3a). When dealing with models that exceeded the spatial confines of the light box, the digitization process was conducted without it. Nonetheless, the paramount consideration was the creation of an environment characterized by exceptional lighting conditions and meticulous control (Fig. 3b).

The photographic capture process involved taking 24 photographs per ring, with a total of 10 rings positioned differently for each object. This deliberate approach was designed to ensure a significant degree of overlap between successive photographs, which surpassed the 70% threshold.

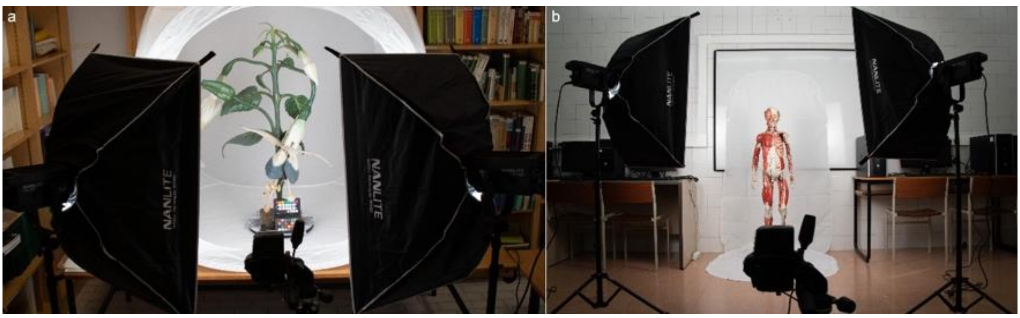

Fig. 3. Photogrammetric capture strategies by rotating the artificial model on a turntable in a controlled lighting environment. a) Model "Fuchsia flower," Dr. Auzoux, 1920. Ref.: MB-USAL-2 belonging to the Botanical Model Collection of the Department of Botany and Plant Physiology of the Faculty of Pharmacy. b) The Model "Anatomy of the Human Body" Dr. Auzoux, 1919, belongs to the "Collection of anatomical waxes" of the Department of Anatomy and Human Histology of the Faculty of Medicine. Both models belong to the University of Salamanca

Image processing: color management and digital development

Once the photographic capture phase was completed, the acquired images were subjected to digital post-processing while in RAW format. Prior to this, careful steps were taken to establish a camera profile, which would ensure precise color management throughout the subsequent stages of image processing. The camera profile generated was in the ICC-TIFF format, a process facilitated using ColorChecker Passport software. An image containing the color chart within the original capture scene was utilized for this purpose.

Subsequently, all captured photographs were imported into Adobe Camera Raw 15.0, an integrated component of Photoshop software. Within this software, the preset camera profile was chosen from the dedicated profiles tab. Following this selection, white balance correction was performed using the neutral gray color positioned at the 18% luminance level of the color chart as the reference point for this correction. Lastly, the processed images were exported in TIFF format, completing the digital development process (Fig. 4).

Fig. 4. a) Creation of camera profile. b) Digital development of the images applying the camera profile and bank balance. Model "Anatomy of the human body" Dr. Auzoux, 1919 belongs to the "Collection of anatomical waxes" of the Department of Human Anatomy and Histology of the Faculty of Medicine, University of Salamanca

Processing of photogrammetric models

The acquisition of photogrammetric models was facilitated by using Agisoft Metashape® Professional software. In preparation for model acquisition, masks were made in the software for each image individually. The need for these masks arises when the background remains identical in several images, while the object has undergone position changes. Once the masks were meticulously made, the initial phase consisted of performing the photographic orientation, using the highest quality settings available. At the end of this phase, a sparse point cloud was generated, which provided an approximation of the volumetric attributes of the object (Fig. 5a).

Afterwards, the process of mesh generation was initiated, employing arbitrary mode depth maps. This step involved consolidating all the points obtained from the previous phase into a unified solid model (Fig. 5b and c). One of the final stages of the photogrammetric reconstruction involved projecting the acquired photographs onto the mesh surface, thereby creating the color texture.

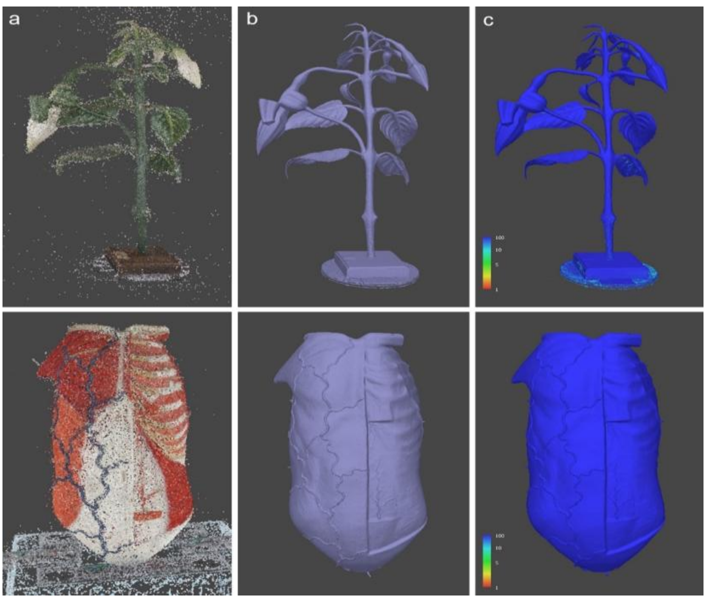

Fig. 5. Process of obtaining photogrammetric models. a) Scattered point cloud. b) Mesh. c) Confidence level. Model "Fuchsia flower," Dr. Auzoux, 1920. Ref.: MB-USAL-2 belonging to the Collection of Botanical Models of the Department of Botany and Plant Physiology of the Faculty of Pharmacy and the model "Anatomy of the human body" by Dr. Auzoux, 1919, belonging to the "Collection of anatomical waxes" of the Department of Anatomy and Human Histology of the Faculty of Medicine. Both models belong to the University of Salamanca

Before commencing the final phase of color texture generation, a thorough analysis of each individual image was conducted. Out-of-focus areas were identified, which could be attributed to the established depth of field and the inherent complexity of the anatomical artifacts under examination. During this phase, after obtaining the mesh derived from the previously masked images, three distinct strategies were rigorously tested. The first strategy involved selectively removing images, typically about half of them, after the mesh was generated. This experimental approach aimed to assess whether such removal would result in an improvement in texture quality. The second strategy entailed employing tools identical to those used in the mask-creation process. This approach was used to carefully eliminate out-of-focus or distorted regions present in each photograph (Fig. 6). The primary goal was to minimize the margin of error in the resulting color texture, thereby enhancing the overall fidelity and accuracy of the outcome. The third strategy consisted of applying an automated function available in the program, specifically the 'defocus mask' option, with the same objective of obtaining better results in the texture.

Fig. 6. a) Out-of-focus areas. b) Generation of masks to cancel out focus areas during texture generation. c) Distorted areas. Model "Chrysanthemum flower heads," Dr. Auzoux, 1919. Ref.: MB-USAL-1, model "Theobroma cacao," 20th century. Ref.: MB-USAL-71 both belong to the Botanical Model Collection of the Department of Botany and Plant Physiology of the Faculty of Pharmacy, and the model "Anatomy of the human body" by Dr. Auzoux, 1919, belongs to the "Collection of anatomical waxes" of the Department of Anatomy and Human Histology of the Faculty of Medicine. All of them belong to the University of Salamanca

3D digitizing by structured light scanning

Characteristics of the structured light scanner

At times when photogrammetry has proven inadequate for faithfully capturing the volumetric characteristics of anatomical models, alternative digitization methods have been employed, specifically structured light scanning. The Artec Space Spider scanner has been utilized for this specific purpose. This device offers a scanning area ranging from 90×70mm at its closest proximity to 180×140mm at its maximum operating distance, enabling precise capture of minute spatial regions. Furthermore, it boasts an impressive accuracy level of 0.05mm and a resolution of 0.1mm, facilitating volumetric registration characterized by an exceptional level of quality, precision, and detail.

Capture strategies

To achieve three-dimensional registration of anatomical sculptures, a methodology in which the artifact remained stationary while being scanned from various viewpoints, typically at a distance of approximately 15-25cm. Despite the satisfactory results provided by the scanner, persistent issues arose during registration, particularly in complex models such as the one depicted in Fig. 2. These challenges stemmed from a combination of factors, including the substantial separation between different groups of branches, the uniformity of the red floral elements in this specific case, and the limited scanning area available. These conditions led to errors and positional shifts in the scanned frames. Consequently, it became imperative to introduce a system of distinctive targets to prevent the scanner from losing reference points, thus ensuring the integrity of the volumetric record.

A diverse array of two-dimensional target systems, often generated through mathematical algorithms, was available. However, due to the equipment used, it was deemed necessary to design them using the FDM (Fused Deposition Modeling) technique with an Ultimaker S5-type machine, tailored to the requirements of the model. The design involved creating a cuboidal structure divided into two halves, each assigned a distinct color, typically gray and red. Within these compartments, various geometric shapes were embedded, each characterized by unique parameters related to position, orientation, and scale, ensuring the individuality of each target. The geometric elements were printed in colors that contrasted with those of the cuboidal base, enhancing recognition by the scanner (Fig. 7). Subsequently, the targets were placed on 3D-printed columns of varying heights, precisely calculated to accommodate the specific needs of the artifact.

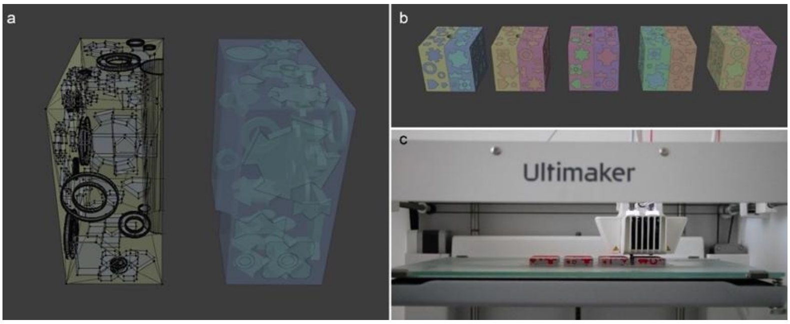

Fig. 7. a) 3D target modeling process. b) Different types of 3D targets.
c) FMD 3D printing process with dual extruder of the Ultimaker S5 machine

Processing of scanned models

The processing of the data obtained during the scanning process was conducted using the Artec Studio Professional 15 software, specifically designed for the Artec scanners. Next, a series of crucial post-processing procedures were undertaken. These procedures included scan alignment, thorough global registration, identification, and removal of frames displaying errors or anomalies, as well as the selection of data points exhibiting atypical characteristics. Once these preparatory steps were successfully executed, the final phases of the post-processing workflow comprised the creation of a polygon mesh representation and the acquisition of texture data (Fig. 8).

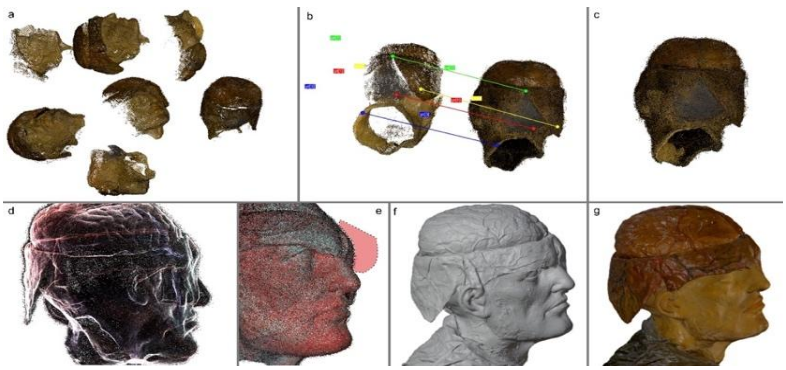

Fig. 8. a) Scans. b) Alignment process. c) Alignment performed. d) Global registration. X-ray vision. e) Elimination of anomalies. f) Mesh. g) Final texture. Model "Anatomical Head," Royal College of Surgery of San Carlos de Madrid, XVIII century. Ref.: MAJP000378 from the Museum of Anatomy "Javier Puerta" of the Faculty of Medicine, Complutense University of Madrid

Results and discussion

3D digitizing by photogrammetry

The digitization of anatomical artifacts employing the capture strategy that involves rotating objects on a turntable within a precisely controlled illumination environment (Fig. 3) has yielded highly satisfactory results. Each captured image has faithfully preserved its essential details, and the careful application of color management has significantly contributed to endowing the resulting model with an exceptional level of accuracy and fidelity. The acquisition of the sparse point cloud and the subsequent mesh generation (Fig. 5) using conventional workflows have also produced favorable outcomes.

As previously mentioned, concerns were raised regarding the quality of the color texture, primarily stemming from the limitations imposed by the depth of field. In response to these concerns, a more meticulous approach was implemented before generating the color texture. One of the experiments involved selectively removing images approximately halfway through the workflow, after the mesh was completed using depth mapping. Although this method showed some improvement, particularly in overall sharpness within the out-of-focus regions (Fig. 9a, b, and c), it was found to be ineffective in more complex areas, resulting in a reduction in quality due to the loss of critical information stemming from the reduction in the number of images (Fig. 9d, e, and f).

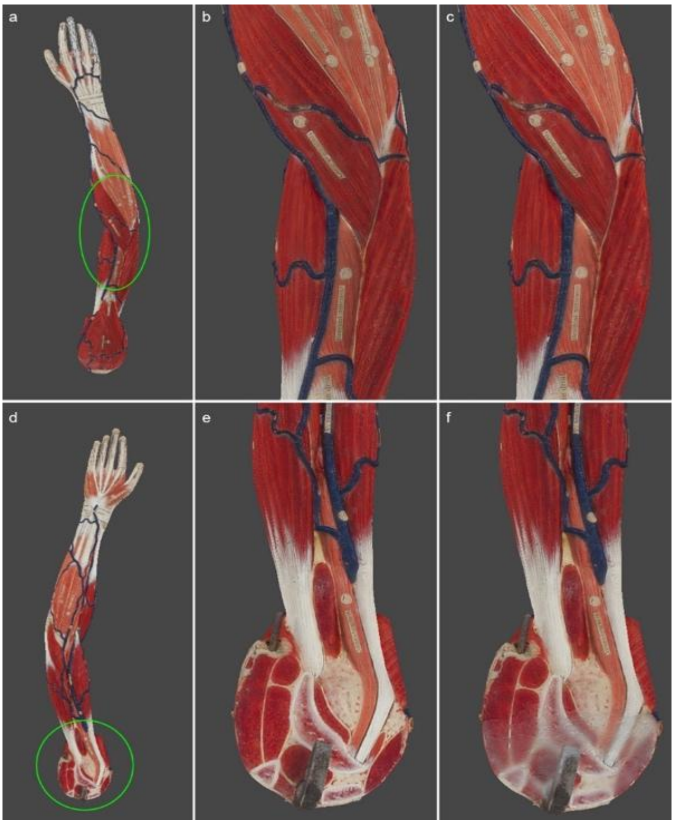

Fig. 9. a, b, d, and e) Texture processed with all the photographs of the captured model. c) Texture processed with half of the photographs of the captured model. In this area, the results improved slightly as the number of images decreased. f) Texture processed with half of the photographs of the captured model. The results in this area were significantly reduced as the number of images decreased. The model "Anatomy of the human body," by Dr. Auzoux, 1919, belongs to the "Collection of anatomical waxes" of the Department of Anatomy and Human Histology of the Faculty of Medicine, University of Salamanca

Therefore, given the randomness of this strategy and the realization that different results would be obtained for each figure, this approach was abandoned in the quest to enhance texture quality.

The second strategy involved the creation of masks to systematically eliminate areas marked by blurriness or distortion (Fig. 6) within each individual image before generating the color texture. This procedure produced remarkable results. The approach enabled the precise capture of even the smallest details, including crucial elements such as labels and numerical markings associated with each anatomical model (Fig. 10).

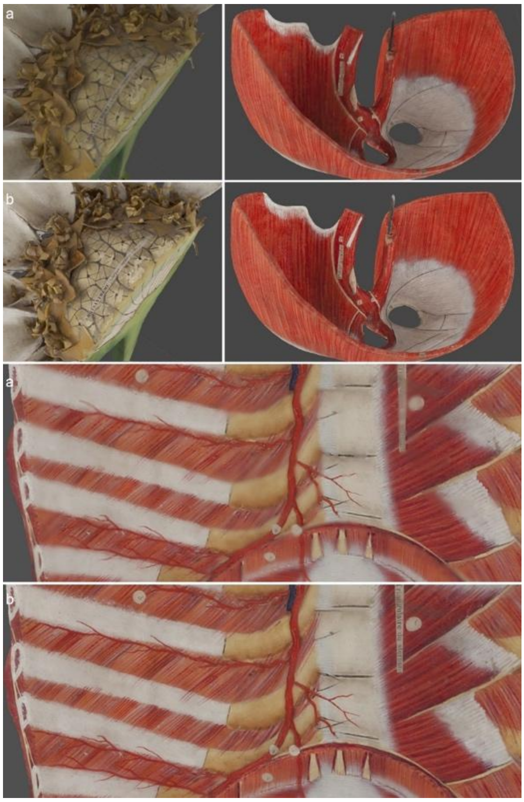

Fig. 10. a) Generation of the color texture with all the images without masks. b) Generation of the color texture with masks to cancel the out-of-focus areas. Model "Inflorescences in flower head of Chrysanthemum". "Dr. Auzoux, 1919. Ref.: MB-USAL-1 belonging to the Collection of Botanical Models of the Department of Botany and Plant Physiology of the Faculty of Pharmacy and the model "Anatomy of the human body" by Dr. Auzoux, 1919, belonging to the "Collection of anatomical waxes" of the Department of Anatomy and Human Histology of the Faculty of Medicine. Both belong to the University of Salamanca

As for the third strategy, which consisted of applying an automatic function available in the program, specifically the ’defocus mask’ option, in general good results were obtained; however, this was not the case for all the models, since in some of them, specifically when there was a greater depth of field, which was very subtle, no clear results were obtained. Given the randomness of this strategy in the face of the difficulties of anatomical artifacts, this strategy has been discarded.

After an effective use of masks in enhancing the quality of the color texture, we experimented with processing the model with the masks at the initial stages of the digitization process, including photo orientation and mesh creation using depth maps. However, it's worth noting that in certain models, this change in methodology led to a noticeable decrease in quality, resulting in errors in the mesh (Fig. 11).

Fig. 11. a) Result of the mesh after processing the model with all the captured images. b) Result of the mesh after processing the model with the masks eliminating the out-of-focus areas. Model "Chrysanthemum inflorescences in flower head". "Dr. Auzoux, 1919. Ref.: MB-USAL-1 belonging to the Botanical Model Collection of the Department of Botany and Plant Physiology of the Faculty of Pharmacy, University of Salamanca

Subsequently, the photogrammetric models were processed in two distinct phases: initially, during the photo orientation and mesh creation phases using depth maps, all images were utilized, and subsequently, during the final color texture creation phase, masks were carefully generated to eliminate out-of-focus areas. This sequential approach was adopted to enhance the overall quality and fidelity of the resulting models.

3D digitizing by structured light scanning

3D targets were meticulously designed, subsequently printed, and strategically positioned alongside the artifact (Fig. 12a). Throughout the scanning process, a portion of these targets, along with a portion of the object, consistently remained within the registration window (Fig. 12b, c, and d). The continuous presence of reference points ensured the comprehensive capture of all features, irrespective of their uniformity. The design and strategic placement of these targets played a pivotal role in facilitating the digitization of the botanical model with the utmost quality and accuracy (Fig. 13).

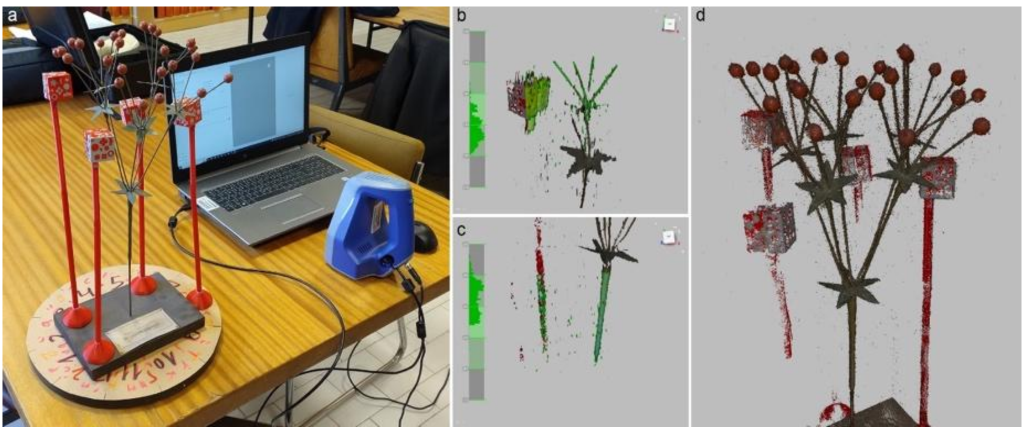

Fig. 12. Scanning process with 3D printed targets. Model "Inflorescence in compound umbel" by Les Fils d'Émile Deyrolle, 20th century. Ref.: MB-USAL-33 from the Botanical Model Collection of the Department of Botany and Plant Physiology, Faculty of Pharmacy, University of Salamanca

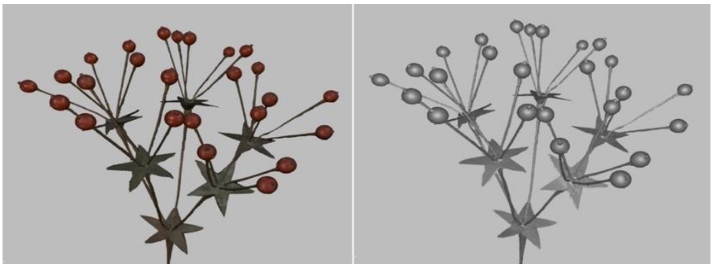

Fig. 13. Model "Inflorescence in compound umbel" by Les Fils d'Émile Deyrolle, 20th century. Ref.: MB-USAL-33 from the Botanical Model Collection of the Department of Botany and Plant Physiology of the Faculty of Pharmacy, University of Salamanca, after completion of scanning

Several anatomical models obtained through the strategies employed in this research are showcased below (Fig. 14).

Fig. 14. a) Model "Fuchsia flower" "Dr. Auzoux, 1920. Ref.: MB-USAL-2 (See 3D model). b) Model "Inflorescence in compound umbel" by Les Fils d'Émile Deyrolle, 20th century. Ref.: MB-USAL-33 (See model 3D). c) Model "Theobroma cacao," 20th century. Ref.: MB-USAL-71 (See model 3D). d) Model "Wheat Spikelet," Dr. Auzoux, 1920. Ref.: MB-USAL-9 (See model 3D). e) "Pea pod," Dr. Auzoux, 1919. Ref.: MB-USAL-16 (See 3D model). The botanical models belong to the Botanical Model Collection of the Department of Botany and Plant Physiology of the Faculty of Pharmacy. f) The model "Anatomy of the human body" by Dr. Auzoux, 1919 (See 3D model) belongs to the "Collection of anatomical waxes" of the Department of Anatomy and Human Histology of the Faculty of Medicine. All of them belong to the University of Salamanca

Conclusions

The main goal of this research is to preserve and promote the educational value of anatomical collections by committing to the highest levels of quality throughout the digitization process, encompassing both the generation of meshes and the acquisition of color textures. Findings revealed a crucial factor in the photographic capture process. It relies heavily on object volume and depth of field, creating a significant challenge in the pursuit of maximum quality in color texture. This limitation arises from the inherent characteristic wherein areas with varying degrees of blur, ranging from subtle to pronounced, hinder the software's ability to accurately align corresponding points in different photographs. Consequently, the final color texture contains out-of-focus and poorly detailed regions.

Methodologies tested to address these issues, relying on image processing, particularly the selective filtering of out-of-focus or distorted regions during the phase preceding the acquisition of the color texture, have effectively resolved the common errors encountered in 3D models. Thanks to this strategy, it became possible to accurately reproduce the anatomical model, characterized by an unprecedented level of quality and fidelity. Furthermore, the use of structured light scanning techniques proved to be a highly valuable supplementary tool for capturing various complex volumetric elements of the anatomical artifacts that photogrammetry couldn't achieve, thanks to the strategic placement of specially designed 3D targets on-site.

In sum, this research not only advances the preservation and dissemination of educational anatomical collections but also offers valuable insights into image processing techniques and 3D scanning applications. This could ultimately enhance the capacity to faithfully and precisely represent our cultural heritage.

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