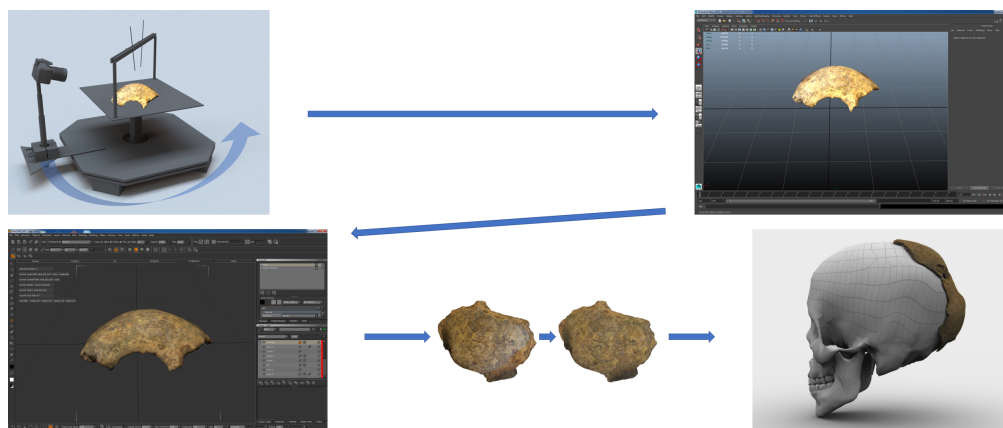


# Streamlining Photogrammetry Reconstructions of Bone Fragments for Bioarchaeological Analysis, Conservation, and Public Engagement

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**Figure 1:** Bone fragment digitisation workflow using practices and applications from the feature film visual effects industry: source photographs of the fragment (here a cranial fragment) are acquired using a photogrammetry rig, the resulting geometry is cleaned up, textures are reprojected and corrected, and the end results are attached to a wireframe model of generic bones (here a skull) for contextualisation.

## Abstract

We present a streamlined workflow for the 3D reconstruction of skeletal fragments, suitable for bioarchaeological analysis as well as public engagement and based on practices and applications from the feature film visual effects industry. Using a low-cost single-camera photogrammetry rig for close range photogrammetry and processing the results using standard 3D asset creation software from the visual effects industry, the resulting 3D models achieve a resolution that is sufficient for the clear representation of bone elements and any gross changes affecting them, such as severe trauma.

## 1. Introduction

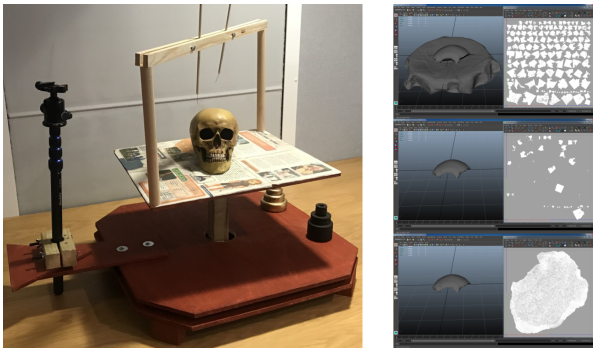
We present the development of an approach and workflow for the provision of an efficient and time/cost-effective pipeline (regarding both data-capture and data processing) for the production of detailed digital 3D reconstructions of fragmented human skeletal remains (Figure 1).

This work was conducted in concert with the “crusader skeleton” project, which involves the digital reconstruction of a single highly fragmented human skeleton recovered from a 13th century crusader mass grave in Sidon (Lebanon) [HDSS\*19]. By employ-

ing practices and applications from the feature film visual effects industry, we have found that the process can be streamlined.

## 2. Photogrammetry in Archaeology and Bioanthropology

The development of digital 3D imaging, associated virtual reconstructions and their application within the cultural heritage sector has expanded the range of tools available for creating and preserving records of all aspects of material culture [GPS14]. Photogrammetry has proven especially useful for archaeology [SM17], where it has been recognised as a viable low-cost alternative to other



**Figure 2:** Left: our low-cost single-camera photogrammetry rig; Right: generated mesh before and after mesh and UV optimization (top to bottom).

methods for 3D digitisation of heritage objects such as bone fragments, with results minimally deviating from 3D models digitised using surface laser scanning [KF14].

### 3. Our 3D Bone Fragment Reconstruction Workflow

The specific software packages we used were ReCap Photo (part of Autodesk ReCap Pro — <https://www.autodesk.co.uk/products/recap/overview>) for 3D mesh generation, the 3D modelling and animation software Autodesk Maya (<https://www.autodesk.co.uk/products/maya/overview>) for mesh and UV layout clean-up and the 3D painting and texturing application Mari (by The Foundry — <https://www.foundry.com/products/mari>) for texture re-projection and clean-up. To optimise the image acquisition process we built a portable single-camera photogrammetry rig, using an orbiting camera attached to the rig for close range photogrammetry (Figure 2, left image).

#### 3.1. Source Image Acquisition

The first step in the process of digitising the bone fragment is taking a number of photographs of the fragment for processing with the photogrammetry software – in our project we have used a Canon EOS 5D Mk. III DSLR camera. There are a number of constraints that need to be taken into consideration during this process to ensure the correct processing of the images by the software. ReCap Photo supports the use of a camera orbiting a stationary digitisation target, which negates the need for an empty, flat and evenly lit background for the photographs, which can be expensive to achieve. As there must be visual overlap between each of the photographs it is necessary to rotate the camera in approximately 5 degree increments. The process can be improved by using our photogrammetry rig, which minimises the area of physical space required and also greatly speeds up image acquisition.

#### 3.2. 3D Model Generation

Using ReCap Photo, the resulting images can be processed to generate a 3D model (mesh and texture) of the target object that can then be processed further with Maya and Mari:

1. **Mesh Cleanup:** Generated meshes tend to include errors, such as holes or the inclusion of parts of the target object’s surroundings, necessitating clean-up of the mesh (here done using Maya) by filling holes and the removal of polygonal faces that are not part of the target object (Figure 2, top right image).
2. **UV layout Recreation:** The 3D mesh created by the photogrammetry software includes a basic UV map/UV layout for all of the geometry, including UV information for redundant elements removed during clean-up, resulting in a fragmented UV map (Figure 2, middle right image) in need of optimization. Re-creating the UV map for the remaining mesh geometry allows the UV layout to dedicate more space of the UV map to the mesh geometry (Figure 2, bottom right image), which in turn allows the final texture resolution to be much higher than, once the textures have been re-projected onto the object.
3. **Texture Re-Projection & Correction:** After the UV layout optimisation, the original texture map generated by the photogrammetry software will no longer work, so the textures need to be re-projected onto the new UV layout. This can be achieved with 6 to 8 of the original photographs (depending on object complexity and the area covered by the photographs) used to generate the mesh and the corresponding virtual cameras that should be exportable from the photogrammetry software. Re-projecting the images onto the UV layout and masking between the projections in Mari to seamlessly blend them together after correcting and balancing colour, brightness and contrast to ensure the projections match one another then generates the final texture map.

### 4. Discussion

Compared to established photogrammetry practices in archaeological recording, our workflow is much less time-consuming (e.g., using our photogrammetry rig, we have found that a single orbit of the camera around the target object is sufficient, resulting in as few as 35 images and averaging at 50 images), requiring fewer processing steps. Nevertheless, 3D models generated with our workflow are more than adequate for public engagement purposes and initial results suggest that the achieved model quality is high enough for experts to recognise and analyse bone elements and gross changes, although the capture of micromorphological characteristics would likely require a higher resolution (sub-0.5mm) and more expensive DSLR camera, which we aim to explore in the future.

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