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Erolin, Caroline; Jarron, Matthew; Csetenyi, Laszlo

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Zoology 3D: Creating a Digital Collection of Specimens from the D'Arcy Thompson Zoology Museum

Caroline Erolin^a, Matthew Jarron^b, Laszlo J Csetenyi^c

^a Centre for Anatomy and Human Identification, University of Dundee, Dundee, DD1 5EH, Scotland, UK. c.d.erolin@dundee.ac.uk

^b Museum Services, University of Dundee, Dundee, DD1 4HN, Scotland, UK. m.h.jarron@dundee.ac.uk

^c School of Science and Engineering, University of Dundee, Dundee, DD1 4HN, Scotland, UK. l.csetenyi@dundee.ac.uk

Corresponding author – Caroline Erolin

Abstract

The University of Dundee's D'Arcy Thompson Zoology Museum houses many fascinating specimens from around the world. Most of them were collected by the celebrated mathematical biologist Sir D'Arcy Wentworth Thompson, the first Professor of Biology at Dundee. 2017 sees the centenary of the publication D'Arcy Thompson's extraordinary book *On Growth and Form*. During 2016 a project to digitise key specimens from the collection was undertaken as part of the centenary celebrations. Smaller specimens were scanned using a microCT scanner, while larger specimens were captured using hand-held structured light scanners. The resulting 3D models were further processed using the software ZBrush before being hosted online via Sketchfab. They were subsequently embedded on a bespoke webpage (<https://www.dundee.ac.uk/museum/collections/zoology/zoology3d/>) as an extension of the existing University Museum Services website. This article goes on to discuss the resulting collaborations and benefits of sharing museum collections online.

Keywords

Digital; microCT; Museums; Scanning; Virtual; Zoology;

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1. Introduction & Context

Sir D'Arcy Wentworth Thompson (1860-1948) was a Scottish biologist and classics scholar. At the age of 24 he took up the first Chair of Biology at what was then University College, Dundee in 1885. During his 32 years in Dundee he founded and developed a large and impressive Zoology Museum, collecting specimens from around the world. Although this building was demolished in the 1950s, a new museum housing many of the surviving specimens was opened in 2008 at the

University of Dundee. Thompson's collection helped to inform his ground-breaking research into the mathematical principles of nature, which culminated in the 1917 publication of his landmark book "On Growth and Form" {ADDIN CSL_CITATION { "citationItems" : [{ "id" : "ITEM-1", "itemData" : { "author" : [{ "dropping-particle" : "", "family" : "Thompson", "given" : "D'Arcy Wentworth", "non-dropping-particle" : "", "parse-names" : false, "suffix" : "" }], "edition" : "First", "id" : "ITEM-1", "issued" : { "date-parts" : [["1917"]] }, "publisher" : "Cambridge University Press", "publisher-place" : "Cambridge", "title" : "On Growth and", "type" : "book" }, "uris" : ["http://www.mendeley.com/documents/?uid=aa320ea2-ef3c-4cb0-8b91-6cc230615655"] }], "mendeley" : { "formattedCitation" : "(Thompson, 1917)", "plainTextFormattedCitation" : "(Thompson, 1917)", "previouslyFormattedCitation" : "(Thompson, 1917)" }, "properties" : { "noteIndex" : 0 }, "schema" : "https://github.com/citation-style-language/schema/raw/master/csl-citation.json" }}. This pioneered the science of biomathematics and has been hailed as "the greatest work of prose in twentieth century science." (Gould, 1992, ix). 2017 sees the centenary of this extraordinary book and such a number of events are taking place around the world to celebrate (<https://www.ongrowthandform.org/>).

The current Zoology Museum is used for a range of learning and teaching activities within the University. It is open to the public one afternoon per week during the summer as well as occasional open days such as at Easter and Doors Open Days. However, due to security and academic requirements, it is not generally open outside of these times. In order to both raise awareness of the collection, as well as to provide wider access, key specimens were digitised during 2016 with a view to making them available online. The range of specimens chosen represents both the diversity of the collection as well as the connection to D'Arcy Thompson and his work. For example, the Emperor Penguin (<https://skfb.ly/PNTt>) was brought back for him from the Dundee Antarctic Expedition of 1892, and is thought to be one of the oldest specimens in existence. The Musk Ox (<https://skfb.ly/PKwW>) and Walrus (<https://skfb.ly/PNuQ>) are examples of specimens collected by the Dundee whalers in the Arctic, while the Sea Otter (<https://skfb.ly/OPMV>) was an animal whose population decline Thompson highlighted as part of an international inquiry. The Nautilus shell (<https://skfb.ly/VuLL>) is perhaps the most iconic example of his interest in mathematical growth patterns. Other specimens were chosen for different reasons – the Thylacine (<https://skfb.ly/OLUz>) being selected by visiting artist Kelly Richardson as part of an art project involving extinct species.

Over the last decade, 3D digital scanning of museum and cultural heritage artefacts has become increasingly commonplace {ADDIN CSL_CITATION { "citationItems" : [{ "id" : "ITEM-1", "itemData" : { "DOI" : "10.2307/27784660", "ISBN" : "01971360", "ISSN" : "01971360", "PMID" : "45526774", "abstract" : "The recent proliferation of commercial three-dimensional digital scanning devices has made 3D scanning, and virtual and physical replication, a practical reality in the field of heritage preservation. 3D scanning produces a high-precision digital reference document that records condition, provides a virtual model for replication, and makes possible easy mass distribution of digital data. In addition to research, documentation, and replication, 3D data of artifacts are increasingly being used for museum collections storage and packing designs. The cost and complexity of 3D imaging technologies have made 3D scanning impractical for many heritage institutions in the past, but this is changing, as an increasing number of commercial systems are being tailored and

marketed for heritage applications. This paper presents a review of the current state of 3D imaging in the cultural heritage field, methods of physical replication, the different systems used in heritage applications, criteria for choosing a system, and the techniques used for working with the data. Attention is given to identifying those objects that are not likely to be suited for 3D scanning. (English) [ABSTRACT FROM AUTHOR] La reciente proliferaci\u00f3n de dispositivos comerciales de escaneo tridimensional (3D) ha hecho que el escaneo en 3D y la replicaci\u00f3n virtual y f\u00edsica sean una realidad practica en el campo de la preservaci\u00f3n del patrimonio. El escaneo en 3D produce un documento de referencia digital de alta precisi\u00f3n que registra la condici\u00f3n, produce un modelo virtual para replicar y hace posible la f\u00e9cil distribuci\u00f3n en masa de los datos digitales. Adicionalmente a la investigaci\u00f3n, documentaci\u00f3n, y replicaci\u00f3n, los datos en 3D de los artefactos est\u00e1n siendo utilizados cada vez con mas frecuencia para dise\u00f1ar el almacenamiento y empaque de las colecciones de museos. El costo y complejidad de las tecnolog\u00edas de imagen en 3D ha hecho que el escaneo en 3D no haya sido practico en el pasado para muchas instituciones de patrimonio, pero esto esta cambiando a medida que un mayor n\u00famero de sistemas comerciales est\u00e1n siendo dise\u00f1ados y mercadeados a la medida para aplicaciones de patrimonio. Este art\u00edculo presenta una revisi\u00f3n del estado actual de la creaci\u00f3n de im\u00e1genes en 3D en el campo del patrimonio cultural, los m\u00e9todos de replicaci\u00f3n f\u00edsica, los diferentes sistemas utilizados en aplicaciones patrimoniales, los criterios para seleccionar un sistema y las t\u00e9cnicas utilizadas para trabajar con lo\u2026",

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an audience online. With over half a million users contributing over a million models, Sketchfab is now the most widely used platform for distributing 3D content (<https://sketchfab.com/about>). Over 500 cultural heritage institutions large and small have joined to date from 51 different countries, making Sketchfab one of the largest virtual museums in the world (<https://blog.sketchfab.com/500-cultural-institutions-joined-sketchfab/>).

2. Workflow

2.1 MicroCT Scanning and Post Processing

Smaller specimens were scanned using a Nikon XT H 225ST microCT scanner, while larger specimens were captured using hand-held structured light scanners (Artec Eva and Artec Space Spider). The resulting 3D models were further processed using the 3D modelling software ZBrush before being hosted online via Sketchfab (<https://skfb.ly/PpUo>), where they were made available for viewing and downloading worldwide under an attribution, non-commercial-share-a-like creative commons licence. They were subsequently embedded on a new webpage (<https://www.dundee.ac.uk/museum/collections/zoology/zoology3d/>) as an extension of the existing University Museum Services website.

Specimens <250 mm in diameter were scanned using a Nikon XT H 225ST microCT scanner based in the School of Science and Engineering at the University of Dundee. A major advantage of such scans is that they can achieve very high levels of detail. The Nikon XT H 225ST has a 2000 × 2000 pixel flat panel detector, measuring 400 mm × 400 mm in size, which is positioned 1130 mm away from the source. This means that for very small specimens a resolution of a few µm can be achieved, but for larger objects (up to 250 mm in diameter, moved closer to the detector to fit in the frame) this drops to about a still more than adequate 125 µm.

To generate a 3D volume, a series of sequential 2D X-ray images were captured using a tungsten reflection target as the specimens were rotated through 360°, using the software Inspect-X. These images were then sent to a 2nd computer (a high performance PC with a 24-core Xeon processor, two GTX970 graphics cards and 128 GB RAM) where they were reconstructed using VGStudio Max version 2.2 (and later using version 3.0) to generate 3D volumetric representations of the specimens. The 'surface determination' feature was used to create the final surface which was exported as stereolithographic file using the 'surface extraction' window. The pre-set 'normal with simplification' was used for all specimens.

In addition to the outer surfaces, the reconstructed volume contains all the information of the interior structure. This was crucial for wet potted specimens such as the Pencil Urchin (<https://skfb.ly/Pv9M>) and useful for others specimens such as the Nautilus Shell and Prairie Dog (<https://skfb.ly/OING>) where visualisation of the internal structures was desired.

The resulting 3D models (.stl files) were imported into the 3D modelling software Pixologic ZBrush (version 4R7) for post processing. Once in ZBrush the geometry of

each model was 'tidied' by deleting any unnecessary data and artefacts as well as repairing and remodelling any missing data. Unnecessary data and artefacts were deleted by first hiding the relevant part of the mesh and then selecting 'delete hidden' under the 'geometry' and 'modify topology' menus. Any resulting holes were filled using the 'close holes' feature also within the 'modify geometry' sub-menu. The meshes were then retopologised using the Dynamesh feature, which recreates the surface with a more optimal geometry that can also be set to a lower polycount where required (Figure 1).

A disadvantage of microCT scanning is that no colour information is captured. This had to be added manually therefore within ZBrush. Good quality photographs were taken of all the specimens which were used to texture the models using the 'Spotlight' and 'Polypaint' features of ZBrush. The 'Spotlight' feature allows for photographs to be projected and painted directly on to the model (Figure 2), while the 'Polypaint' feature allows for manual painting of the model. Despite retopologising the models, they remained too complex to create satisfactory UV maps (a UV map allows a 2D texture map to be projected onto a 3D image) and as such they were uploaded to Sketchfab without. As Sketchfab is capable of loading the vertex colours associated with the .obj file this was not a major problem. The only slight issue being that in order for the colour textures to look sharp, the polycount of the models had to stay reasonably high, usually between 400,000 and 1 million.

2.2 Structured Light Scanning and Post Processing

Specimens >250 mm in diameter were scanned using either the Artec Space Spider or the Artec Eva structured light scanners. The Artec Space Spider can achieve a resolution of up to 0.1 mm and was used on specimens of up to around 60cm (such as the Long-beaked Common Dolphin Skull (<https://skfb.ly/VLwH>)). The Artec Eva can achieve a resolution of up to 0.5 mm, but is better able to scan larger specimens such as the African Forest Elephant Skull (<https://skfb.ly/PPNH>)). Both scanners were used in conjunction with Artec Studio 11 professional software. All of the specimens scanned in this way required turning over in order to scan all of the surfaces, resulting in a minimum of two scans per specimen (Figure 3). Artec Studio 11 was used to first run fine and global registrations of the scans before using the 'auto-alignment' feature to align them. So long as each scan had enough overlap with the others this worked well. On the few occasions where this wasn't the case, scans could be manually aligned by selecting pairs of locations. The aligned scans were then fused using the 'sharp fusion' feature with the 'fill holes' option set to 'watertight'.

Unlike the microCT scanner, both Artec scanners were able to capture photographic texture in addition to geometry. Once fused, the texture was added to the models using the 'texture' tab within Artec Studio 11. All scans used for the fusion were used for the texture. The options were left at their defaults with 'generate texture atlas' and 'in-paint missing textures' selected. A map size of 1024 × 1024 was used. Once created, the texture maps were exported along with the .obj mesh as a .jpeg file.

When imported into ZBrush, the models captured using the Artec scanners came with ready-made UV maps allowing for the .jpeg file to easily be added as the texture map. It should be noted however that the .jpeg image required flipping vertically prior

to loading within ZBrush. Once the models with textures were loaded into ZBrush the texture map was converted to Polypaint (using the 'polypaint from texture' feature) in order for it to be further edited along with the geometry. The geometry was 'tidied' and retopologised in the same way as for the models from the microCT scanner, while the colour texture was corrected for harsh shadows and missing data using the Polypaint feature. Unfortunately the process of tidying and retopologising the geometry resulted in the UV maps being deleted. However, as Sketchfab supports .obj vertex colours this wasn't considered to be a big problem.

2.3 Sketchfab

Sketchfab was chosen as the platform to host and distribute the 3D models due to its ease of use and notable support for cultural heritage institutions. The University of Dundee Museum Services were provided with a free Business account under the user name of 'University of Dundee Museum Collections'. The models were uploaded directly from ZBrush using the built in Sketchfab uploader.

Once uploaded to Sketchfab a number of parameters were altered using the '3D settings' tab. These included: positioning the model and setting the field of view to around 30°; adding a custom background featuring the University and Museum logos; applying standard studio lighting across all models; and setting the material properties to suit the specimen, for example a more matte finish was chosen for bone while a glossy finish was chosen for the Blaschka glass model (<https://skfb.ly/OHHU>). In addition, two models, the Blaschka Glass and the Prairie Dog were set to transparent.

As described in the sections above, colour texture was in the form on vertex colour on the model itself rather than as a separate texture map. This meant the polycount of the models was quite high, usually between 400,000 and 1 million. This could result in longer loading times which would be problematic on older or lower powered devices. In order to compensate for this, the larger models were duplicated at a lower polycount and labelled as being for mobile devices.

Sketchfab allows for work to be easily shared under a Creative Commons license. All models from the University of Dundee Museum Collections were made available for download under an attribution, non-commercial, share alike license. Once hosted on Sketchfab models can easily be embedded on websites and social media and even downloaded for 3D printing.

2.4. Results

Finally, the models were embedded within a bespoke webpage. This was created as an extension of the existing University of Dundee Museum Services website. The landing page features thumbnails of all available scans (Figure 4). When these are clicked on, the user is taken to a page containing the 3D model and information about the specimen. The site went live in January 2017 and can be viewed at: <https://www.dundee.ac.uk/museum/collections/zoology/zoology3d/>

To date the Sketchfab site of the University of Dundee Museum Collection has over 470 followers with 41 discreet models uploaded (to date). Of the 41 models online,

20 are skulls, two are bones, four are mounted skin preparations, 11 are Blaschka glass models, one is an insect, and one is a shell. The collection has received over 20,000 views from more than 25 countries, with over 2000 downloads having taken place. The model sizes vary considerably from the smallest at 963KB / 59.2K Polygons / 29.6K vertices, to the largest at 30.7MB / 1.1M Polygons / 1M vertices.

The models are being used in a variety of learning and teaching initiatives including by the University of Queensland, who are incorporating them into their level three vertebrate anatomy and evolution module, and the organisation 'Museum in a Box' who will be including one of the skulls in their school outreach program, where museum specimens are 3D printed and taken in to the classroom (<http://museuminabox.org/>). As well as being used for learning and teaching activities, the project has also led to a number of exchanges with external researchers. For example, a researcher in Integrative Biology from the Conway Institute of Biomolecular and Biomedical Science at the University College Dublin contacted us about the Blaschka glass model, to inform us that it had been wrongly labelled and to share with us information regarding D'Arcy Thompson's original order of models in 1888. We are also sharing the raw CT data with them to assist in their research and endeavour to rebuild the D'arcy Thompson Blaschka collection. Another expert contacted us regarding the identification of the Elephant skull. This had previously been assumed to be that of an Indian Elephant, but we were informed that it actually belonged to an African Forest Elephant (*Loxodonta cyclotis*).

While the main body of work is now complete, it only represents a tiny fraction of the estimated 4,200 specimens in the collection. Going forward it is hoped that students will get involved in scanning more specimens to be added to the collection so that it might continue to grow. For example, students on the University of Dundee's MSc in Medical Art visit the museum as part of their programme of study and are trained in a variety of scanning and digital modelling modalities. A number of these students are already involved in producing more content for the project.

In addition to the online material, 3D printing of the specimens is underway. The University of Dundee like many Universities has a 3D printing facility on site (DJCADMake). The models are being printed using an Ultimaker 2 3D printer with PLA filament. Where possible specimens will be printed at life size, however for some, such as the elephant and rhinoceros this isn't practical and as such scale models will be produced. These models will be used by Museum Services both for school outreach programmes and to allow visitors to the museum to have hands-on experience of the objects.

3. Discussion and Outlook

It is important for all museums to value their visitors, and over recent years the concept of what constitutes a visitor has been evolving. Online visits to museum websites are now far outpacing physical visitation {ADDIN CSL_CITATION { "citationItems" : [{ "id" : "ITEM-1", "itemData" : { "author" : [{ "dropping-particle" : "", "family" : "Dodge", "given" : "R", "non-dropping-particle" : "", "parse-names" : false, "suffix" : "" }], "container-title" : "MUSE: The voice of Canada\u2019s Museum Community.", "id" : "ITEM-1", "issue" : "1", "issued" : { "date-parts" : [["2016"]] }, "note" : "NULL", "page" : "40-45", "title" : "Technology \u2014 Are Museums Keeping

Pace?", "type": "article-journal", "volume": "35" }, "uris": ["http://www.mendeley.com/documents/?uid=6c714a7f-48fc-4345-86aa-f04dc0f8d4a9"] }], "mendeley": { "formattedCitation": "(Dodge, 2016)", "plainTextFormattedCitation": "(Dodge, 2016)", "previouslyFormattedCitation": "(Dodge, 2016)" }, "properties": { "noteIndex": 0 }, "schema": "https://github.com/citation-style-language/schema/raw/master/csl-citation.json" } }.

The role of the museum website is also changing. No longer are they simply a source of visitor information regarding opening times etc., but they frequently host searchable databases of images and models and even complete virtual exhibitions.

Large museums such as the Smithsonian and British Museum have sizable collections of 3D models available online (<https://3d.si.edu/browser> and <https://sketchfab.com/britishmuseum>). However, it is at least equally important for smaller museums, especially those with limited opening hours to have a strong online presence. Sharing materials in the way outlined here can greatly increase the visibility and reputation of a small museum.

It is hoped that the workflow presented can be used to help other museums in developing their own online collections. Use of microCT and Artec surface scanners allowed for particularly high-quality scans to be captured. However, the later part of the workflow (post-processing in ZBrush and using Sketchfab to host and embed models) could also be used for models created by other means such as photogrammetry {ADDIN CSL_CITATION { "citationItems": [{ "id": "ITEM-1", "itemData": { "DOI": "10.1016/J.CRPV.2016.08.003", "ISSN": "1631-0683", "author": [{ "dropping-particle": "", "family": "Marine Fau, Rapha\u00ebl Cornette", "given": "Alexandra Houssaye", "non-dropping-particle": "", "parse-names": false, "suffix": "" }], "container-title": "Comptes Rendus Palevol", "id": "ITEM-1", "issue": "8", "issued": { "date-parts": [["2016", "11", "1"]] }, "page": "968-977", "publisher": "Elsevier Masson", "title": "Photogrammetry for 3D digitizing bones of mounted skeletons: Potential and limits", "type": "article-journal", "volume": "15" }, "uris": ["http://www.mendeley.com/documents/?uid=66504ab6-5fdd-3718-81a7-8ca3eebc2e46"] }], "mendeley": { "formattedCitation": "(Marine Fau, Rapha\u00ebl Cornette, 2016)", "plainTextFormattedCitation": "(Marine Fau, Rapha\u00ebl Cornette, 2016)", "previouslyFormattedCitation": "(Marine Fau, Rapha\u00ebl Cornette, 2016)" }, "properties": { "noteIndex": 0 }, "schema": "https://github.com/citation-style-language/schema/raw/master/csl-citation.json" } }, which can be used where scanners such as those used here are not available.

Setting up and taking the microCT scans took around 1.5 hours per specimen, but for much of this time the scanner could be left unattended. The Artec scans were a little quicker, taking closer to half an hour to set up and scan, depending on the complexity of the specimen. The most time-consuming aspect of the workflow tended to be the post-processing. In Artec studio this could take up to an hour per specimen as the aligning and fusing of scans could be time consuming and is impacted by the graphics card and amount of RAM available. However, much of this time involves waiting for the software to run a process, so other work can be carried on while this is taking place. Finally, the degree to which the scans were 'tidied' and textured in ZBrush was variable and took between 30 minutes and two hours per specimen. This could be reduced however if the textures were imported and not altered. The software described above is not particularly difficult to learn, especially

for this specific workflow, meaning that it could potentially be used by artists and non-artists alike. This is especially the case where the texture is already captured either by the scanner or via photogrammetry, meaning that this doesn't have to be added manually.

Uploading editing the models on Sketchfab was quick and easy. Most models uploaded in under five minutes and could then be edited via the Sketchfab website. Adding a bespoke background and changing the lighting and material properties to best display the models took around another five minutes. The models could then be embedded on our own web page by simply copying and pasting some html code.

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Robert Jackson and Alasdair Napier, DJCADMake

References

{ADDIN Mendeley Bibliography CSL_BIBLIOGRAPHY }

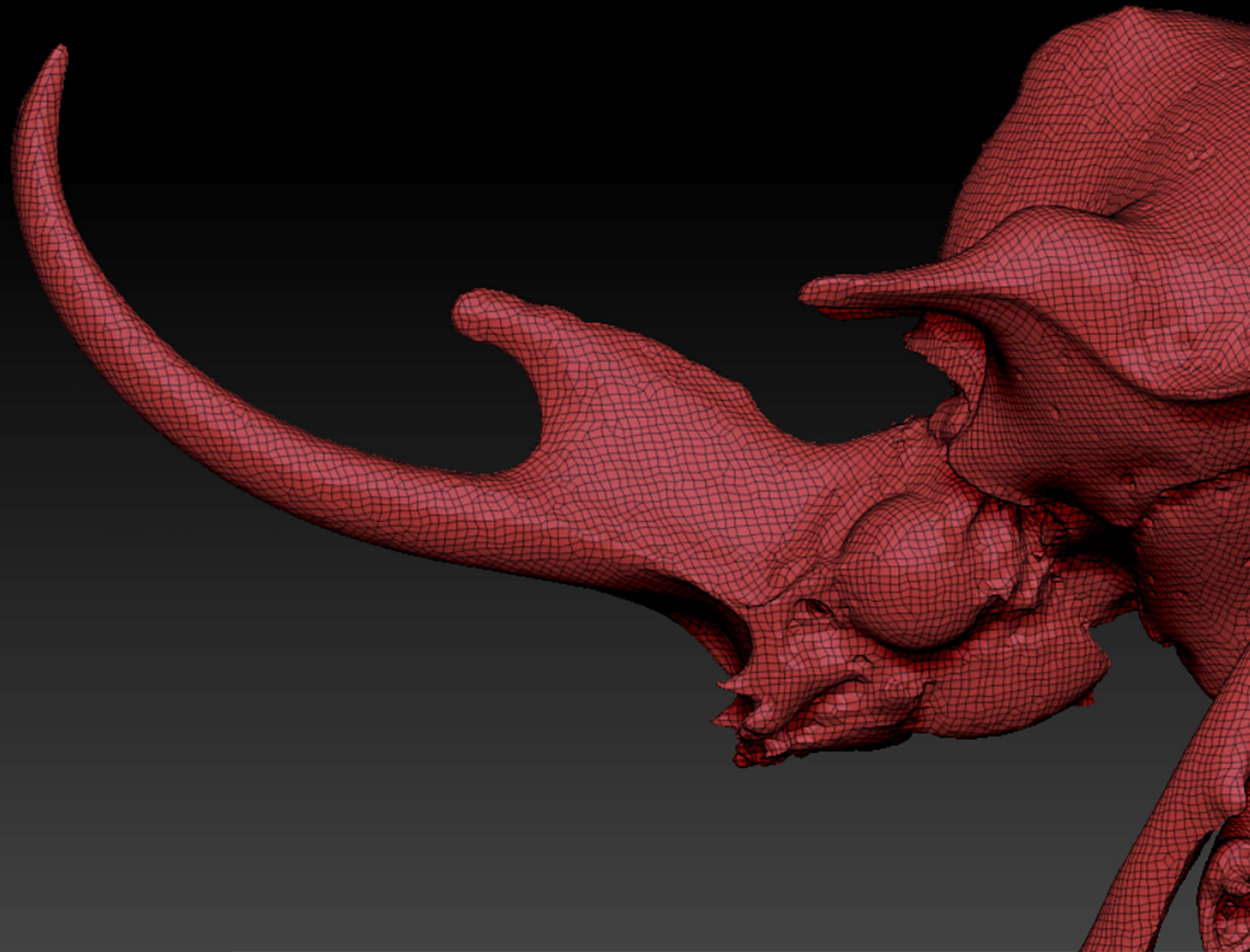
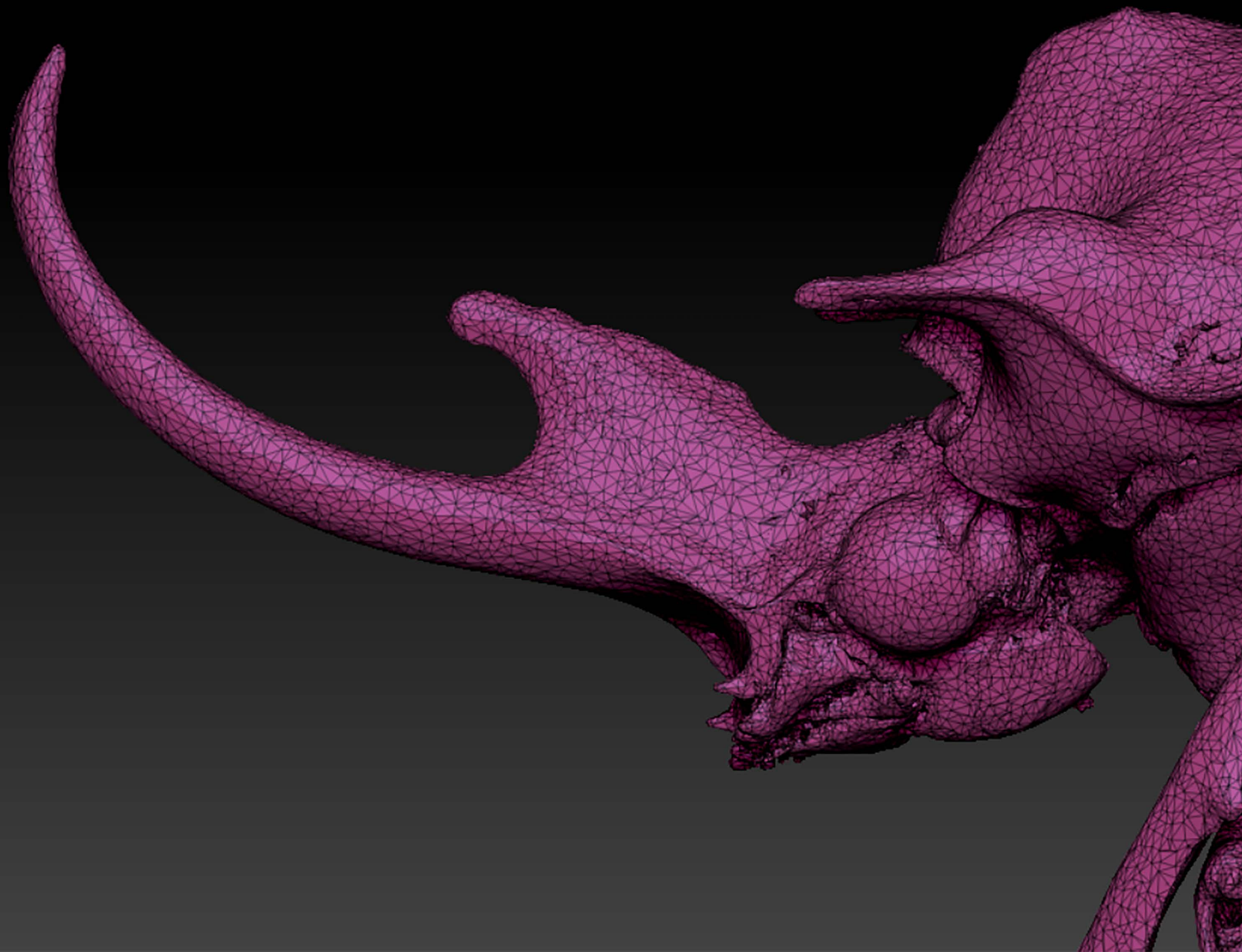
Figure Captions for: Zoology 3D: Creating a Digital Collection of Specimens from the D'Arcy Thompson Zoology Museum

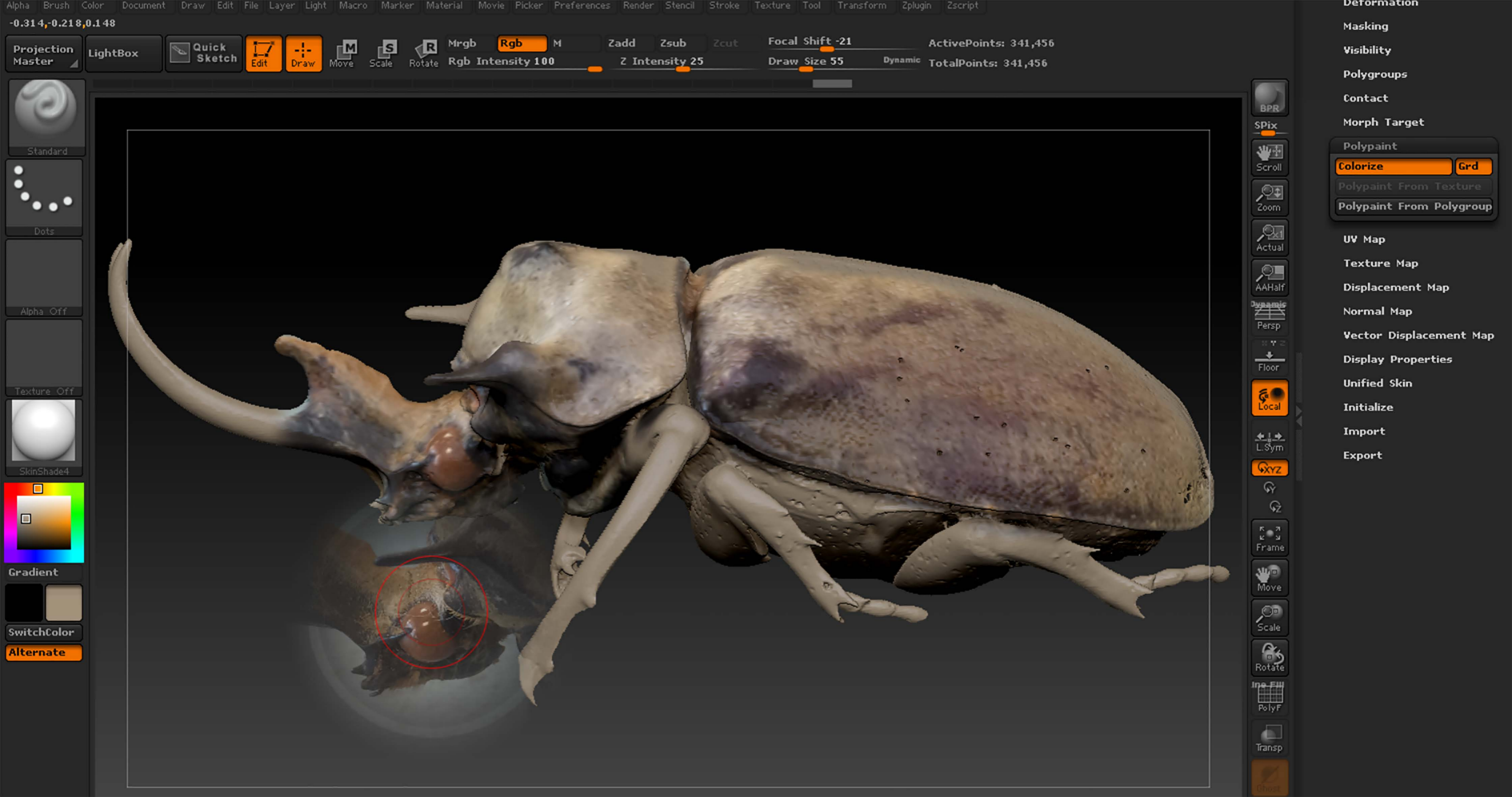
Figure 1: microCT scan of a Rhinoceros Beetle before and after being retopologised using the Dynamesh feature within ZBrush. This process recreates the surface with a more optimal geometry that can also be set to a lower polycount.

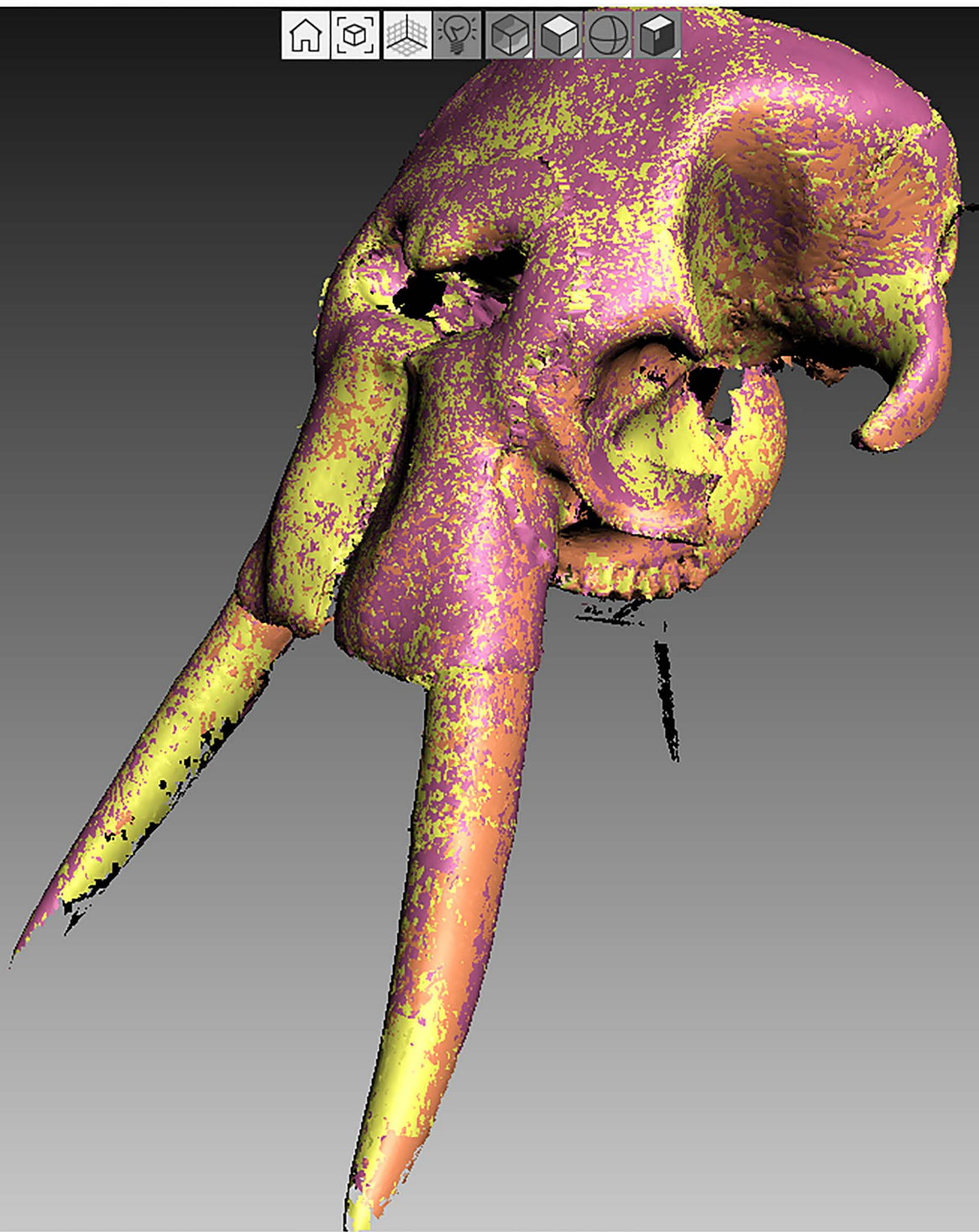
Figure 2: Screenshot showing microCT of a Rhinoceros Beetle being textured using the 'Spotlight' feature of ZBrush which allows for photographs to be projected and painted directly on to the model.

Figure 3: Screenshot from Artec studio 11 Professional showing multiple scans. The four scans in this case are represented as an overlay of four different colours.

Figure 4: Screenshot of the landing page for the bespoke webpage, created as an extension of the existing University of Dundee Museum Services website. The landing page features thumbnails of all available scans.

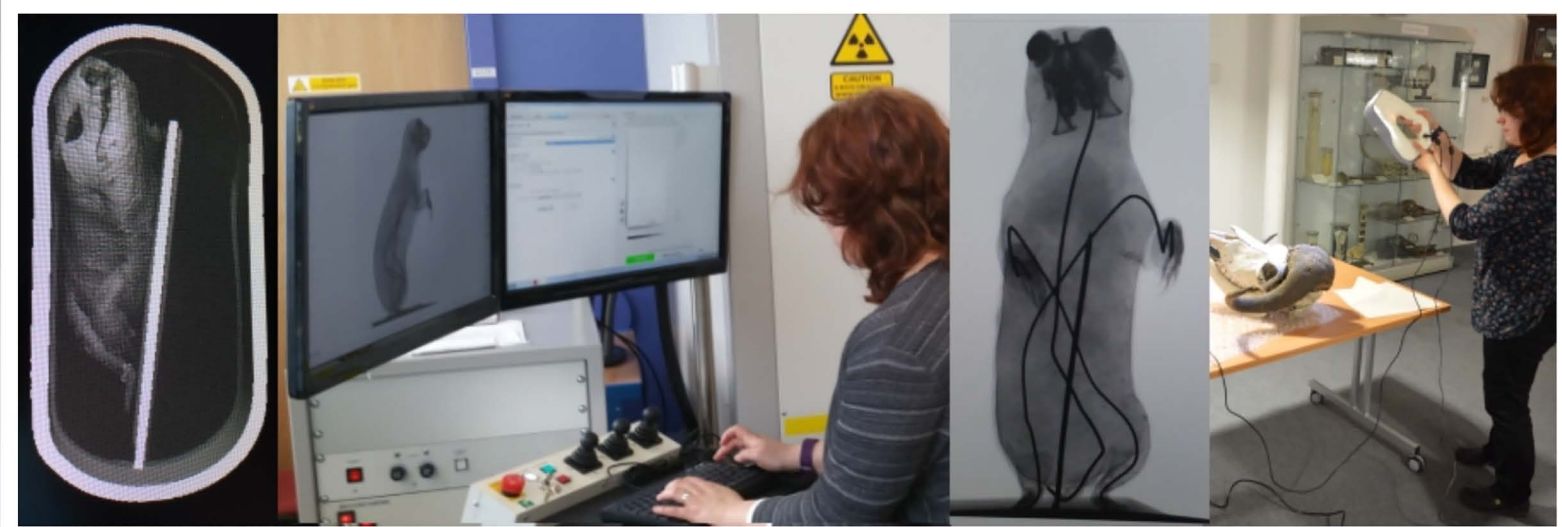






| | ID | Title | Load... | Total | Max ... |
|--|----|-------|---------|------------|---------|
| | 1 | Scan1 | 709 | 709 / 721M | 0.3 |
| | 2 | Scan2 | 311 | 311 / 292M | 0.3 |
| | 3 | Scan3 | 522 | 522 / 511M | 0.2 |
| | 4 | Scan4 | 703 | 703 / 725M | 0.3 |

D'Arcy Thompson Zoology Museum 3D



About the Project

In 2016 we began a project in collaboration with the University's [Centre for Anatomy & Human Identification](#) to digitise specimens from the D'Arcy Thompson Zoology Museum. Smaller specimens were scanned using a Nikon XT H 225ST micro CT scanner, while larger specimens were captured using hand-held structured light scanners (Artec Eva and Artec Space Spider). The resulting 3D models are hosted online via [Sketchfab](#) and are available for viewing and downloading worldwide under a creative commons licence.

Click on any of the images below to be taken to a page containing the 3D model and information about the specimen.

