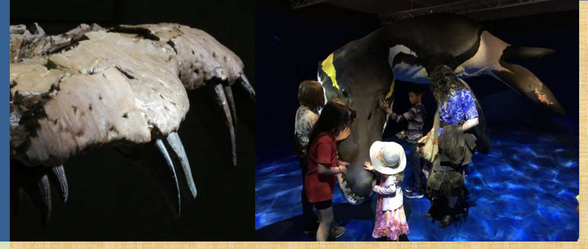

Mounting the Type specimen of *Pliosaurus carpenteri*, an 8m-long fossil pliosaur (extinct marine reptile) skeleton for Bristol City Museum, including the 3D-printed 1.8m-long skull.

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Abstract

The type specimen of *Pliosaurus carpenteri* from Westbury in Wiltshire, UK, is the most complete skeleton known of this extinct genus, with an estimated body length of 8m. The whole skeleton was mounted by the authors for display at Bristol City Museum & Art Gallery in 2017 for the first time since its excavation in 1994.

Mounting the heavy postcranial bones from scratch on suitable steel metalwork was relatively straightforward. However, the fossilised skull is 1.8 m long, very heavy and consists of many very fragile pieces. Mounting the real skull in position would have required a large amount of unsightly supporting metalwork that also would have obscured some very interesting pathology on the palate inside the mouth.

One option was to CT scan the individual skull pieces and use the subsequent digital models to make 3D-printed replicas. This way of making a lighter replica skull would present less risk to the specimen than traditional moulding and casting and could possibly be quicker and cheaper.

Importantly, the process would also provide detailed 3D morphological data of the skull's internal anatomy for the first time – invaluable to ongoing research. But would the resulting replica look real or horribly fake? The 3D-printed skull would have to match the real mandible and postcranial bones in texture and colour.

Methods and materials

1. At the start of the project the skeleton (Fig 1) was laid out and Steven Dey used a structured light scanner to record the three dimensional morphology of all the bones. He then made low resolution 3D digital models of each one.

2. The in-house designer at Bristol Museum (Simon Fenn) in collaboration with the palaeontologist who formally described the specimen (Dr Judyth Sassoon) used these digital models of the bones to build an accurate articulated 3D skeleton to scale to visualise how it would look on display and how much space it would take up (Fig 2).

3. Nigel Larkin made the metal mount to support over 100 kg of fossil bones and the replica skull to mm precision, following the CAD plan of the skeleton supplied by Bristol Museum. This had to be constructed in a fashion that would allow easy assembly and dis-assembly as the work was undertaken in his conservation studio in Shropshire and the mount needed to be transported to Bristol in sections. The main structure (8m long and 2.5m high) was made from steel tubes and flat steel strips etc shaped using blacksmithing skills and MIG welded together (Fig 3). The vertebrae of the spine and the various small ribs, gastralia and limb bones were held in place with rods and/or strips of brass shaped to the outline of the bones and brazed to one another (Fig 4). Where required, the metalwork was lined with inert Plastazote foam to protect the bones.

4. The structure was given extra rigidity with six thick Perspex sheets cut to indicate the flesh outline of the body including the four limbs. The bones (Fig 5). were held to the Perspex with brass strips and rods brazed together.

Figure 1. The fossil skeleton laid out with a curator for scale.

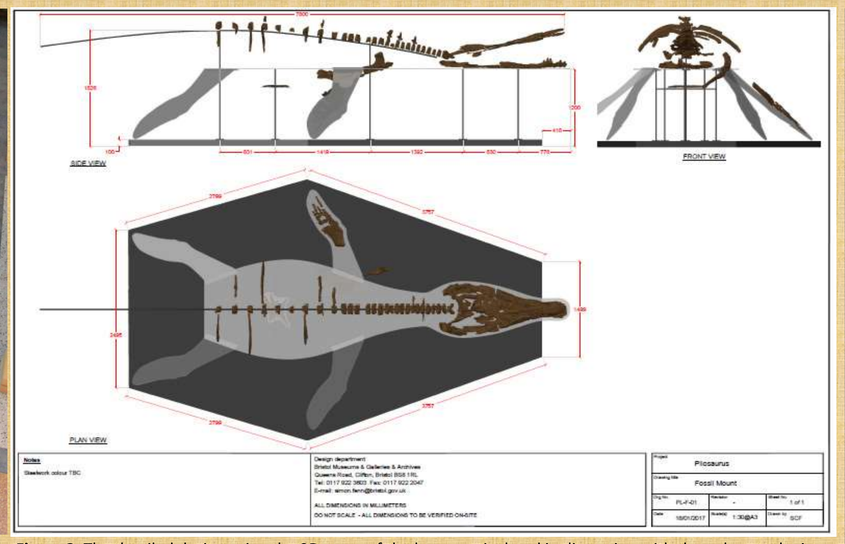

Figure 2. The detailed design using the 3D scans of the bones articulated in discussion with the palaeontologist.

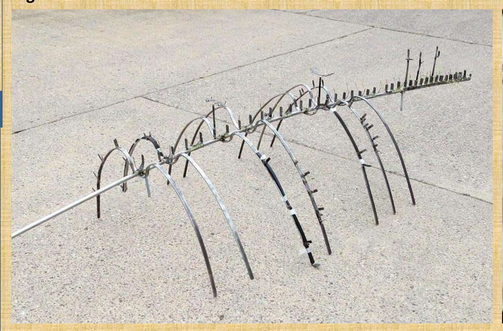

Figure 3. The steel frame made to hold the larger ribs and vertebrae in place, not yet positioned on the upright supports.

Figure 4. Brass strips and rods brazed together to hold smaller bones in place.

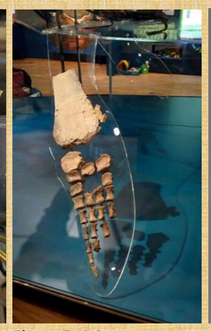

Figure 5. A Perspex fleshed-out limb.

Figure 6. CT scanning the tip of the pliosaur skull at the Royal Veterinary College.

Figure 7. The high-resolution 3D digital model of the skull and mandible generated from the CT scans.

Figure 8. The pieces of the pliosaur skull freshly 3D printed in gypsum at ThinkSee3D.

Figure 9. The 1.8 m-long 3D printed skull positioned above the real fossil mandible, lying on a Perspex sheet, on display.

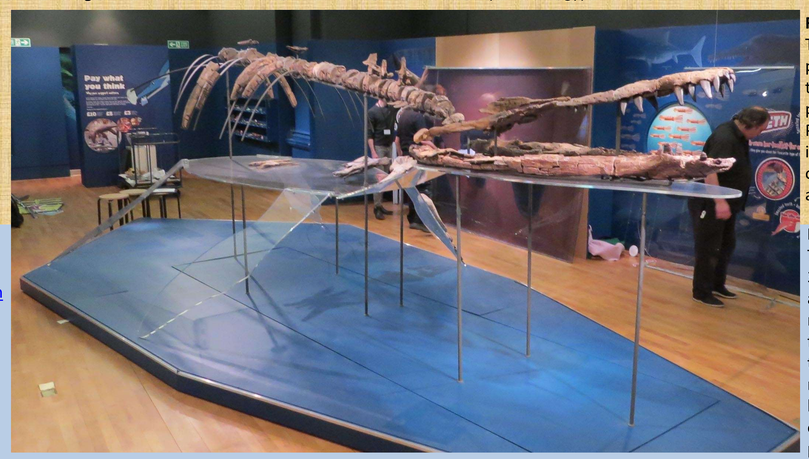

Figure 10, left. The mounted partial skeleton of the 8m-long fossil pliosaur with the Perspex sheets indicating the 'flesh outline' of the animal.

Figure 11, right. The 1.8m-long 3D-printed skull above the real mandible of the fossil pliosaur. Note the foam-lined metal supports holding the pieces of the mandible in place.

5. The skull and mandible are the most significant part of any animal diagnostically and are the parts that people most want to see. Also this skull has some interesting pathology where elements were broken in life and healed over time. The skull, however, was found in many pieces. Many of these were thin and fragile yet the combined weight was in excess of 25 kg. Mounting this part of the fossil would have required unsightly supporting metalwork which would have obscured the interesting pathology.

Therefore a replica was needed, leaving the original skull to be displayed elsewhere upside-down so that the interesting pathology of the palette could be seen more easily. A replica skull could have been made by carefully moulding the individual pieces to make casts but many fragments are fragile and moulding can be invasive and risks damaging bones. Instead, we CT-scanned the skull pieces (Fig 6) and used the data (Fig 7) to 3D print the replicas in gypsum (Fig 8). As well as being safer for the bones, CT scanning provided researchers with data about the internal structure of the specimen for the first time.

These 3D printed models were articulated by gluing the smaller pieces together and then drilling holes lengthwise through the thicker pieces for two long thin steel rods that held them all in place. The 3D-printed gypsum was then painted to match the real bone of the skull with artists acrylic paints (Figs 9, 10 & 11) .

Discussion & Conclusion

This project required several months of scanning, digital modelmaking, designing, blacksmithing, welding, grinding, soldering, brazing, 3D-printing and painting.

There are many ethical issues to consider when mixing 3D-printed models with real specimens. Firstly, the public should be aware of what is 3D printed and what is real by noting it in the display text. Also, we need to be aware that freshly 3D printed materials 'off-gas' and we should have an idea of their stability and likely longevity. This Pliosaur display was only temporary and the skeleton was not sealed in a display case with the 3D prints. However, in other exhibitions real bones are being mounted with elements that are 3D-printed. The authors use what we consider to be the most benign and stable of 3D printing materials: a gypsum-based product which provides a dry, matt texture that is very appropriate for replicating fossil material and more recent bones. We are actively testing the stability and longevity of this and other 3D printing materials with colleagues such as Gabrielle Flexer in Wiltshire through undertaking Oddy tests etc.

This first thing visitors saw as they approached the skeleton was the huge open mouth and then the rest of the skeleton stretching down along the room. Satisfyingly, many palaeontologists were invited to the opening night and none of them realised that the skull was a replica until they read the display text. Most importantly, the palaeontologist Dr Judyth Sassoon, who has studied the specimen for over two decades, was delighted with how the mount brought the bones to life.

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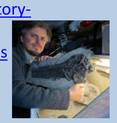

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