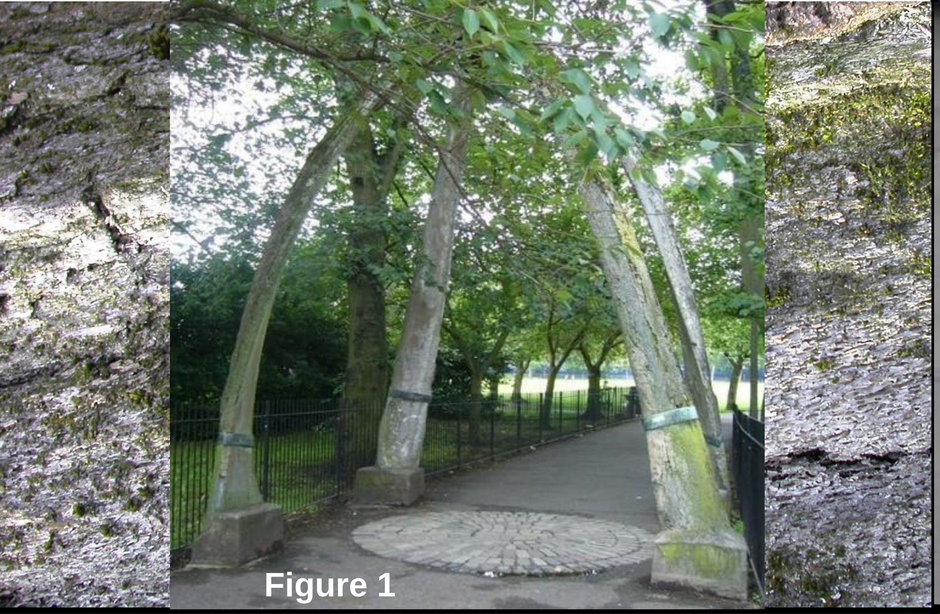

Figure 1

State of the Arch: The recent removal, conservation, 3D scanning and reinstatement of the large 135-year-old 'double' whalebone arch located in The Meadows in Edinburgh, UK.

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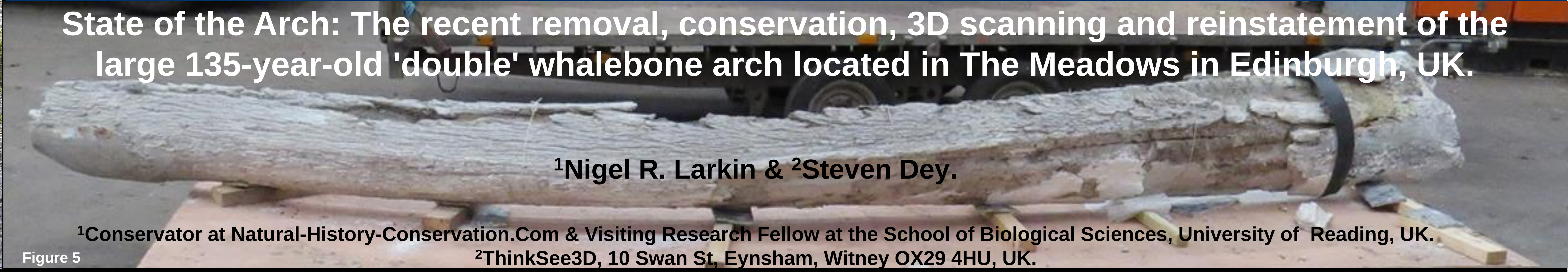

Figure 5

ABSTRACT

Edinburgh's famous double whalebone arch comprising four huge bones made from the lower jaws of two very large baleen whales (see image above) originally formed part of a stand manned by the Shetland and Fair Isle Knitters at the International Exhibition of Science and Art which took place in Edinburgh in 1886 (Redman, 2004). The knitters gifted the arch to the city after the exhibition and it became a well-loved local landmark in 'Jawbone Walk', one of the entrances to the park known as The Meadows.

However, after withstanding the Scottish weather for over 130 years without protection but with occasional patchy repairs, the bones had deteriorated to the point that they were no longer considered safe to walk under. Large areas of bone had rotted away or fallen out, as had some old repairs. The four bones – all about 6 meters long and weighing around a quarter of a ton each - were carefully removed and allowed to dry out, and then were assessed, cleaned, consolidated and repaired with a bespoke lime mortar (including NHL2 lime that would ensure the fills were breathable and relatively flexible).

After conservation work was complete, each bone was 3D scanned in detail before being given protective coats of casein-infused limewash. The scaled 3D digital models of the bones were particularly useful for designing the new supportive metal armature that will hold the bones securely in place when they are reinstalled. Just as importantly, the digital 3D models will be useful for conservators in the future to asses the degree of degradation of the bones from weathering compared to the point in time when the scans were undertaken, after the conservation work was completed.

In due course, these scans could even allow the bones to be replaced with identical replicas to save the original specimens, either by 3D printing them in a suitable medium, or by being cast in bronze. The conservation work had to take into consideration the large volumes of bone loss, how different materials would respond differently to constantly fluctuating environmental conditions and how the bones would be moved and handled, considering their large size and weight.

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METHODS AND MATERIALS: remedial and preventive conservation

State of the bones: The arch had been displayed outside for over 130 years (fig 1). The surfaces of the bones were largely covered in algae and moss. Beneath this, much of the protective, denser, outer bone had weathered away. Repairs had been undertaken in the past with materials such as concrete, mortar and resin but some of these old fills had fallen off. Portions of the bone had begun to peel away. The structure was carefully dismantled and two separate teams of conservators attempted the conservation project before it was passed to Nigel Larkin.

Figure 2, left. The bones had to be transported using a flatbed lorry with a crane.

Figure 3, below. The bones were lifted and turned using gantries, chain hoists and cloth slings.

Handling: The large, heavy, fragile bones (each about 6m long and each weighing a quarter of a tonne) were transported from Edinburgh to Nigel Larkin's conservation facility in Shropshire. They were well wrapped for the journey in thick foam and bubble wrap and secured on wooden blocks covered in foam on the back of a Hiab Lorry with a crane (fig 2). The bones were lifted and turned as required during cleaning and conservation using suitable cloth slings and I-beam that spread the load, in turn attached to chain hoists hanging from two metal gantries. Each item was capable of safely lifting one tonne (fig 3).

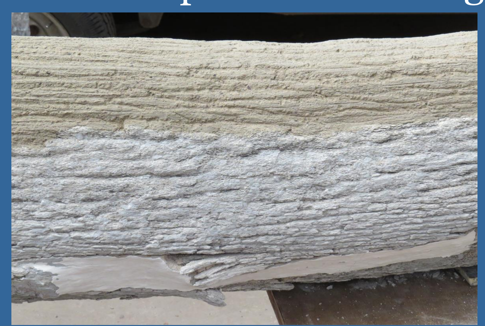
Cleaning: The bones had erroneously been treated with several layers of white lime wash by previous workers (fig 4). This had to be painstakingly removed by scraping with scalpels. Old gap fills that were loose were removed gently with small chisels and hammers. Some simply fell out. Some old resin gap fills were extremely well attached to the bone and if removed would have taken a layer of bone with them. These were left in place. The bones were then cleaned with soft brushes and vacuum cleaner.

Figure 4, left. Removing the old casein limewash from the bone surface with scalpels.

Consolidation: The bones were treated with several applications of Mowital B30H in Isopropanol at 2.5% to increase the strength of the friable spongy internal bone surfaces, so that the materials used to fill the massive areas of bone loss would have something more robust to adhere to.

Gap filling: Massive areas of bone loss had to be filled to protect the internal spongy bone that had been exposed and which was more vulnerable to damage by further weathering (see fig 5, the banner above). Gap-filling materials would have to react as closely as possible to how the bones would react to changes in the surrounding environmental conditions. Given that the arch was to be reinstated outside in the park where it had stood for over 130 years the only candidate was lime mortar. But if this did swell and shrink at a different rate from the bones, the mortar could not be allowed to fall off and potentially hit people below (the arch was positioned over a pathway). Therefore, in areas of major bone loss stainless steel screws were securely emplaced and thin galvanized wire woven between them before the mortar was applied around these.

New mortar: Various lime mortar specialists were consulted about the most appropriate mix to use. As a result, NHL2 St Astier hydrated lime was mixed with washed and well graded sharp sand and a little Portland cement, at a ratio of: 9 parts sand to 3 parts lime and 1 part cement. This should be relatively flexible and allow the bones and mortar to 'breathe'.
The lime mortar was applied to the bones after moistening the surface with a misting of water. The top surface of the mortar was textured to mimic the adjacent bone surfaces (fig 6). The mortar was covered with plastic so that it dried slowly and would be less prone to cracking and separating from the bone.



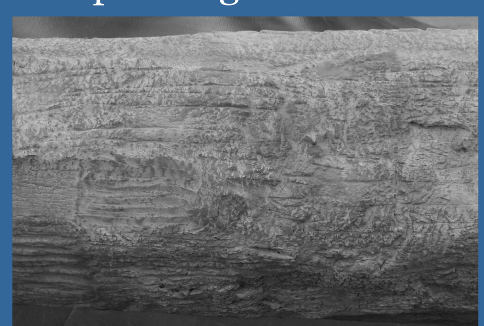


Fig 6 above left: modelled mortar (upper portion) and real bone (lower portion). Fig 7 above right: the bone treated with the wash.

Protective limewash: The bones were given several layers of protective casein-infused limewash designed specifically to match the natural colour of the weathered bones surfaces. Two colours were applied, the final one to highlight the texture of the bones (fig 7). This protective limewash is not permanent, however, and will need to be refreshed every few years.

METHODS AND MATERIALS: 3D scanning & 3D digital models

Photogrammetry: When the lime mortar had fully set, but before the new limewash was applied, each bone was 3D scanned in detail using 3D photogrammetry. Photogrammetry is a computational method that generates detailed colour 3D digital models of a specimen or an object using multiple input digital photographs (taken from many angles in orbits around the target). The outputs of the method capture the 3D geometry as a digital model including a detailed photographic surface texture (with sub-millimetre precision). This gives photogrammetry models their photographic appearance (see figure below).

Photogrammetry is particularly well suited to 3D modelling large textured objects, such as these jawbones. Firstly, because the method relies on surface texture details to compute 3D depth. Secondly photogrammetry allows large objects to be scanned in a piece-by-piece fashion and at a close distance. It is not necessary to image the whole length of the bone in one photograph in order to create the digital model. This advantage of photogrammetry (i.e. being able to create a whole model from photos of many parts) is easy to overlook, it often makes modelling 3D specimens that are difficult to access or to manipulate (as in these whalebones) relatively straightforward. In addition, valuable 2D images can be derived from the 3D model of the whole object that have none of the issues associated with conventional photography such as depth of field, lighting, shadows and lens issues.

Fig 8, above. 3D photogrammetry model of bone 2 with full colour texture.

Data: Scanning very large objects, like these 6m long bones, presents challenges for all 3D scanning methods. This is because highly detailed objects with large surface areas results in very large models from a data perspective. Once models go beyond 2Gb they become very difficult to view and manipulate on typical computing hardware making sharing data more difficult.

With photogrammetry the model can be generated as a whole or in sections at any size. Unnecessary geometry can be 'decimated' or removed from the model using topology-sensitive remeshing algorithms which reduce the overall data size of the models without losing 3D detail. This process was done on the whale bones.

Storage of the finished 3D digital models for future reference is an important consideration and one that incurs a cost. They can be stored locally on an organisations network or preferably for data preservation reasons in an online repository or both. This could be as straightforward as a generic online drive such as is provided by Google or Microsoft or on a platform designed specifically for storing and sharing 3D models such as MorphoSource or Sketchfab. Sharing 3D online means that specimens can be easily and cheaply seen and studied by remote clients, experts or by the wider community.

In the case of the whale bones each was modelled separately and shared on the online Sketchfab platform as well as sent to the client via a Google drive. In addition, to aid the reconstruction process, the whole digital whalebone arch was recreated digitally 'in-situ' before and after restoration. This helps to conserve information about how the arch looked before and after conservation.
Perhaps sometime, decades into the future, when the original arch becomes too degraded to remain in-situ outdoors, these digital models could be used to create 3D printed or CNCed replicas of the bones. As this process could be repeated it provides a way to permanently represent the arch physically for future generations to enjoy.

Fig 9, above. The whale bones after conservation work and 3Dscanninng, digitally reconstructed as a 3D digital model of the arch.

CONCLUSIONS

The Digital 3D models of each of the bones is a record of the specimen's current condition after conservation. This provides a benchmark to which the real bone can be compared in the future to assess the extent of any deterioration in their condition over the years. These models are also proving useful to the engineers constructing the external metal supports that will be required to safely reinstate these bones as an arch in The Meadows in Edinburgh. Without a supporting structure, these bones cannot be considered to be safe if reconstructed as an arch. Also, at some point in the future these digital 3D models could be used to cast replicas of the bones in bronze or another medium that would last far longer than the bones themselves. In the meantime, the bones look much better than they have done for many decades and are now much safer for the public to enjoy.

REFERENCES

Redman, N. 2004. Whales' Bones of the British Isles. Redman publishing, 417 pp.