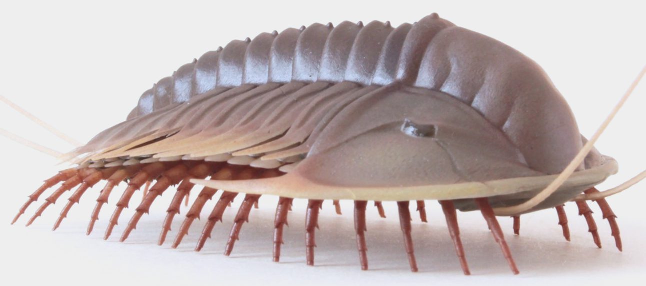

Recreating a trilobite in life-size using 3D printing

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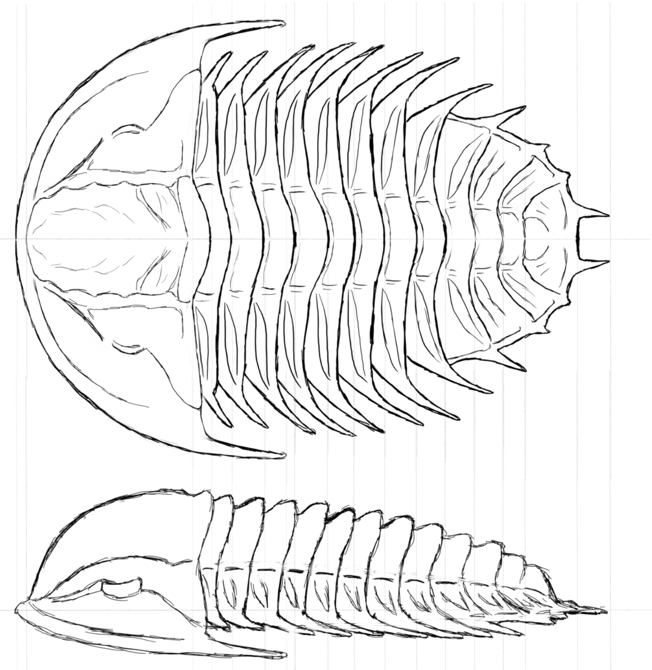
Abstract

Three-dimensional life reconstructions of extinct animals have been popular as several metre-high sculptures ever since the famous Crystal Palace Dinosaurs were unveiled in the 1850’s. Although our scientific understanding of the creatures changed over time, our desire to picture prehistoric animals as physical models did not. Until recently fabricating accurate or at least plausible models even of small organisms was a matter of huge effort, time and money. However, innovations such as 3D modelling software and 3D printing are increasingly available for home use. They open the door for researchers and private people alike to model, sculpt and pose extinct animals with high precision, and to accurately produce them as physical objects which can be explored not only by eye but also by hand. As the design is all done virtually, no limitations are set for the effort invested into the reconstruction.

Here I present the typical workflow of creating such a reconstruction by the example of the Cambrian trilobite *Olenoides serratus* in life-size. Starting by researching the species to be reconstructed, I cover the modelling, posing, preparation for printing, the printing itself as well as the assembly. The whole reconstruction was performed using free and mostly open source software on a home PC and a consumer 3D printer. The resulting model is painted by hand and finished. It illustrates how easily highly detailed models of life reconstructions can be produced today by a private person.

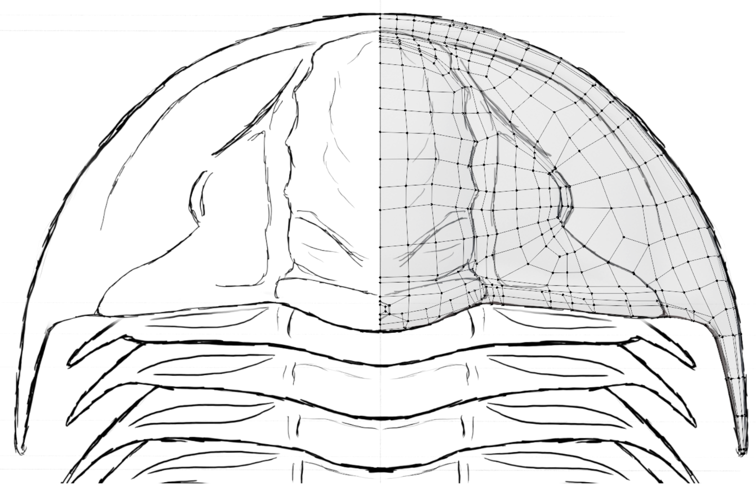
Preparation

At the beginning, the goal is to collect all information needed to construct the digital model. Most importantly, the exterior shape of the animal should be clear before modelling starts. *Olenoides serratus* is well documented and several specimen feature exquisite soft-body preservation[1,2]. After collecting photographs, camera lucida drawings and descriptions of fossilised specimen, 2D drawings are sketched as a starting point for 3D modelling. For this model of *Olenoides serratus*, the dorsal view is based on USNM 65510 and lays down the basic proportions of the animal. The body shape in lateral view is estimated from comparison with different trilobite species and drawn to match the dorsal view.



3D modelling

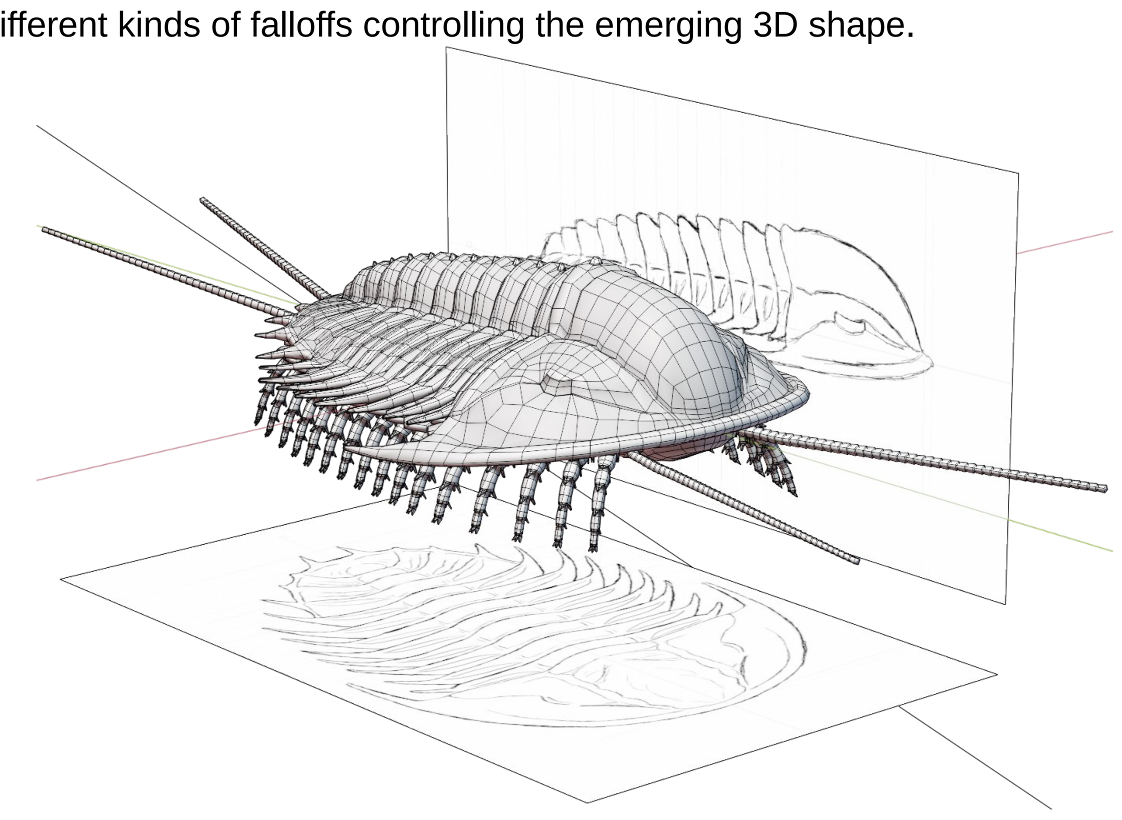
The 3D model is created in Blender[3], an open-source 3D computer graphics software package. Modelling in Blender is mostly based on polygon meshes. This means that the smooth, organic shapes of *Olenoides serratus* are approximated by polygons in the virtual 3D space. To build the model, the 2D drawings are imported as planes into Blender, scaled and positioned appropriately for Blender’s top and side view. Using the mirror modifier, only one side of the trilobite has to be modelled manually.



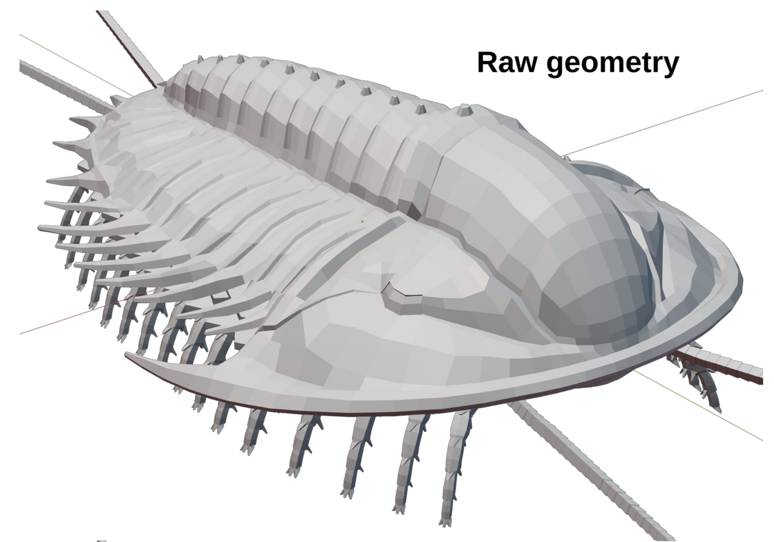
Modelling starts with the dorsal surface of the cephalon. Flat polygons are created in the x,y-plane, following the shape described by the drawing in the background. This step is critical, as it defines the topology of the 3D model, e.g. the flow of polygon edges along the shape of the object. Ideally all surface features such as creases, ridges, bends and edges are parallel to polygon edges. The edge flow of the cephalon is mostly defined by the border of the glabella, the eyes and facial sutures. Clean and balanced topology is important for later steps like sculpting, and makes it easy to use the model for texturing and virtual animation.

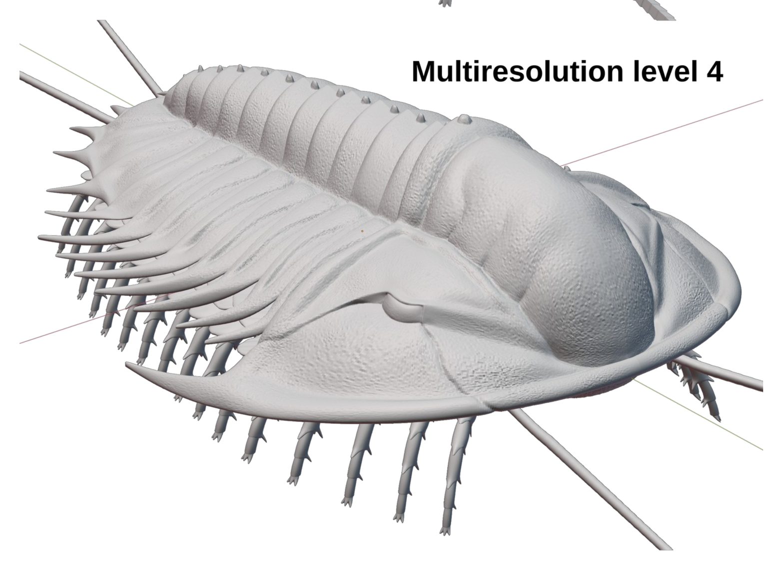
To make all future manipulations as easy as possible, the shape of the animal is defined with just as many vertices as necessary to capture all features. However, the difference in edge density over the model as a whole should not be too high, otherwise adding detail in the later sculpting phase is inefficient. After covering the cephalon with polygons in dorsal view, height is added by dragging vertices only along the z-axis. Tools like proportional editing help, as they enable the user to quickly manipulate a large number of vertices at once, with different kinds of falloffs controlling the emerging 3D shape.

This process is repeated for all dorsal surfaces. Only one thorax segment is modelled from scratch, and copied for the remaining segments, with slight changes made to fit the reference drawings. The ventral surfaces are added after joining the segments together. A limb prototype is modelled directly after a camera lucida drawing from Whittington (1980)[2], and duplicated and modified for the remaining limbs.



The result of the vertex modelling step is a coarse representation of the animal, with large, visible, flat surfaces due to the finite size of the polygons. For 3D rendering, the faceted look can be limited by tricks such as smooth shading. For the purpose of 3D printing, however, the final result is a copy of the actual geometry of the virtual 3D model. The faceting can only be reduced by adding more vertices.





This can be done in a reversible way via the multiresolution modifier in Blender. It allows to subdivide each face of the mesh into smaller ones by cutting in half each existing edge and connecting the resulting vertices. Several iterations (“levels”) of subdivisions can be added. Moreover, the resulting shape can be smoothed, resulting in the desired roundness. The general shape can still be controlled only by manipulating the vertices of the base model.

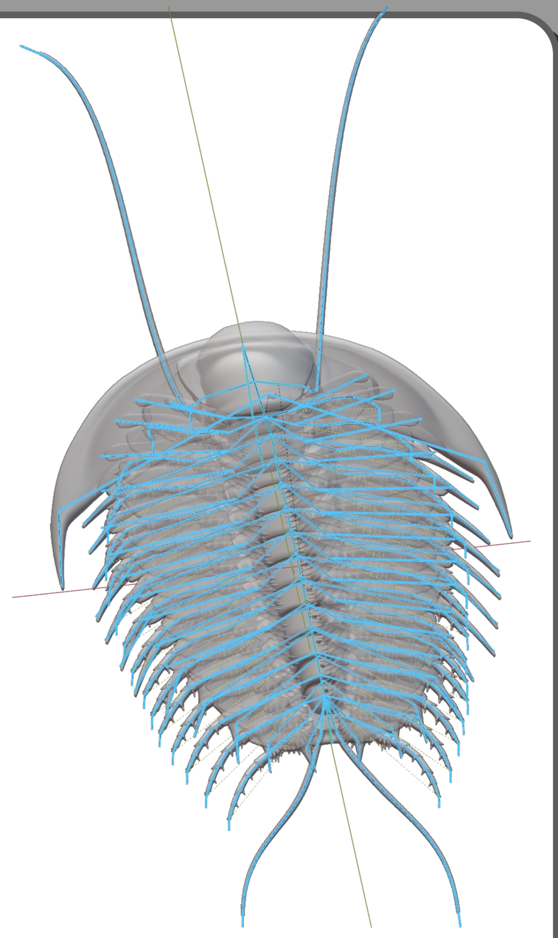
For the model of *Olenoides serratus*, multiresolution level 4 is used. The new, additional vertices serve as a base to sculpt in fine detail. This process is similar to sculpting with clay. The cursor is used to press, grab and push onto the model to change its shape, with various tools for fine control. In this way, creases are refined and deepened, fine corrections of the shape are performed and the surfaces of the exoskeleton are covered with a rough structure. With a body length of under 7 cm, sculpting smaller details is not necessary as the result is limited by the finite resolution of the 3D printing process.

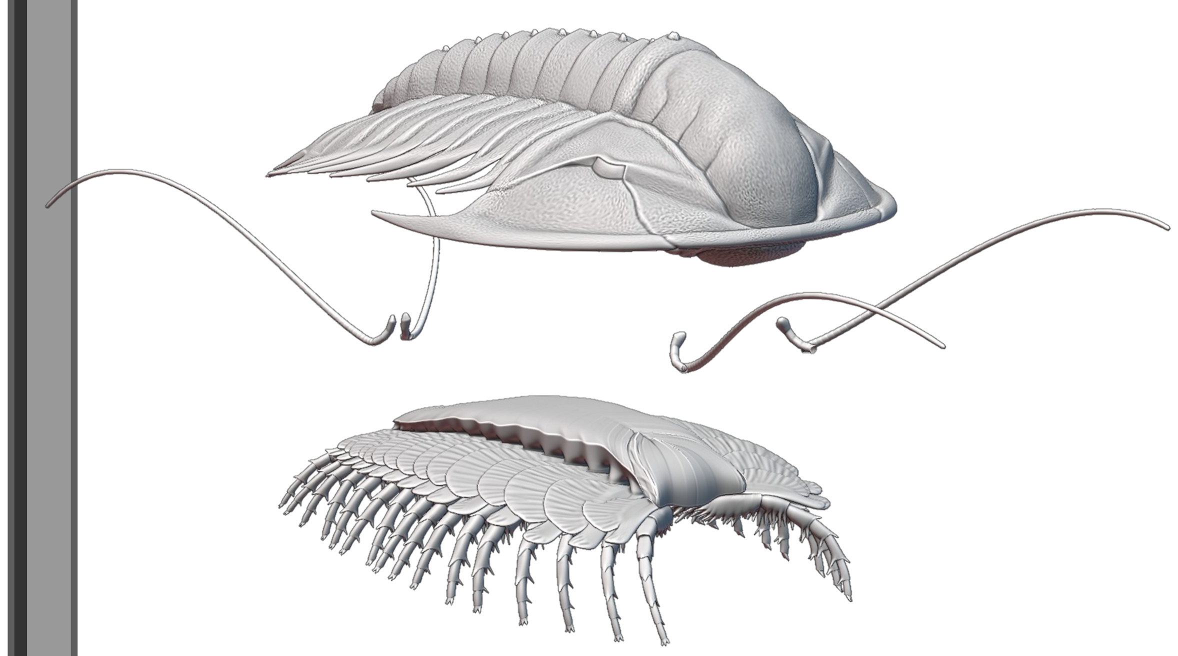
1: Whittington, H. B. Trilobites with appendages from the Middle Cambrian, Burgess Shale, British Columbia. Fossils and Strata, No. 4: 97-136 (1975)
2: Whittington, H. B. Exoskeleton, Moult Stage, Appendage Morphology, and Habits of the Middle Cambrian Trilobite Olenoides serratus. Palaeontology 23, 171–204 (1980)
3: https://www.blender.org/

Rigging and posing

The model is created in a very static and unnatural posture which makes it easy to model. The final product should have a more dynamic and natural appearance. To manipulate the pose of the body, legs and antennae, a virtual armature is created. It is composed of individual “bones”, which can be rotated later. Each limb has 7 bones to allow all segments to move accurately, and another target bone. Inverse kinematics (IK)-constraints allow to control all bones of the leg only by placing the target bone to a place to which the leg shall point. This set-up simplifies the control of the limbs considerably. The cephalon, the pygidium and each thorax segment have one stiff bone, such that the body can only bend at the joints. The antennae are controlled by “bendy-bones”, which follow a Bézier curve between two control bones.

The model of *Olenoides serratus* is “parented” to the armature. This process assigns weights to each vertex describing the influence of each bone’s movement on the final position for the vertex. This is mostly done automatically. Afterwards, the armature can be posed, controlling the deformation of the model in a reversible way.





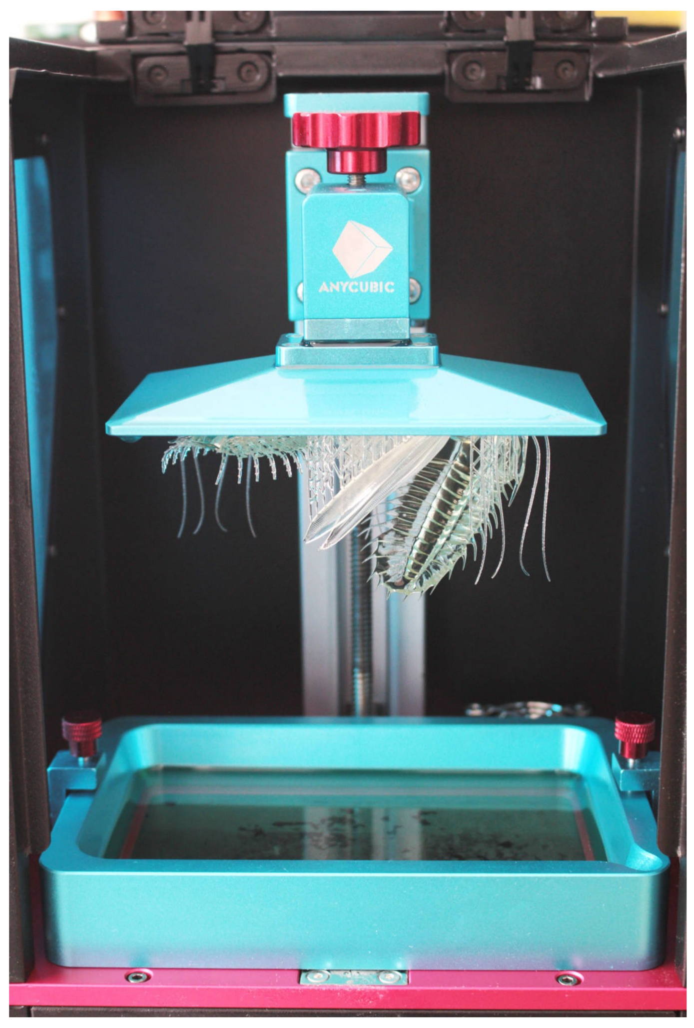
Preparation for printing

Before 3D printing, the model is separated into several parts which allows to easily paint all areas later, and to circumvent the limitations of the printing technology. Because of the linear, additive printing process, all overhangs and horizontal surfaces must be supported from below. The printer software can be used to add support columns, but they damage detail around the contact area. This is taken into account when splitting the model into pieces.

3D printing

The parts are imported into the printer software, oriented for maximal self-support. Necessary support structures are added. The printer software is used to “slice” the model, meaning it cuts horizontal sections through the model to determine which areas of each print layer have to be filled with material. *Olenoides serratus* is printed on an Anycubic Photon[4] printer. It uses the Digital Light Processing (DLP) technology, where UV-light shines from below into a bath of resin. This resin cures when exposed to UV-light. An LCD screen controls the curing layer-wise with the results from the slicing process. A motor-driven build plate steps up after each layer has been added.

The Anycubic Photon’s LCD screen has a resolution of 47 µm, and the layer thickness is set to 50 µm. Clear resin from Anycubic[5] is used with 11 s normal exposure time and 60 s for the bottom five layers to safely attach to the build plate. The printing process takes approximately five hours. Afterwards, the parts are cleaned in a bath of isopropyl alcohol and the support structures are removed, before exposing them again to UV light to cure the resin completely.



Painting and assembly

The six parts of the trilobite model are carefully cleaned and imperfections around the support structure attachments are sanded off. Test-fitting is important to make sure that the parts can be assembled without problems after painting.

Acrylic paint is used to add colour to the model. It is applied in very thin layers using an airbrush with a 0.2 mm nozzle for fine details. Floor polish is added to the paint to add transparency. Pictures of extant horseshoe crabs were taken as reference for colouring. The dorsal surfaces are shaded in tones of grey, brown and ochre, the ventral side and gills are kept mostly grey. The limbs are painted in a transparent mixture of brown and ochre. The application of thin layers makes it possible to control the opaqueness of all areas of the model. The gills, limbs, antennae and the ventral, soft-body areas as well as the thin borders of the exoskeleton are kept in varying degrees of translucency. Afterwards, the parts are assembled using cyanoacrylate adhesive.

Conclusions

Recreating a life-sized reconstruction of *Olenoides serratus* and similarly sized animals as a 3D printed model is feasible today by anyone with access to a computer and a consumer 3D printer. As shown on this poster, the whole process can be performed using only free and open source software, with the exception of the printer software. The current generation of consumer DLP 3D printers offers a great combination of high resolution, simplicity in usage and affordability. The build size is limited to smaller objects, but more recent printers are already available with larger build volumes, while keeping the resolution in the 50 µm range. In combination with the advancing capability of open source photogrammetry software, 3D printing is an ideal tool for replicating palaeontological subjects.

The files to print your own trilobite are available at:
https://www.thingiverse.com/thing:4601819

4: https://www.anycubic.com/products/anycubic-photon-3d-printer
5: https://www.anycubic.com/collections/uv-resin/products/translucent-uv-resin-for-photon-series