TeMoG – Instruction manual

Introduction

Tentacle-inspired soft actuators are a basic component class used for many soft robotic systems and tasks that include both manipulation, locomotion, and positioning.

The TeMoG (Tentacle Mold Generator) tool makes it possible to easily generate STL files for 3D printing molds for casting soft robotic tentacles. The tool allows the user to change all dimensions of the tentacle and easily obtain a mold for casting a custom soft robotic tentacle.

Design

The different mold parts for casting the tentacle are generated from a script in OpenSCAD, an open-source geometric CAD software program that can be downloaded for free.

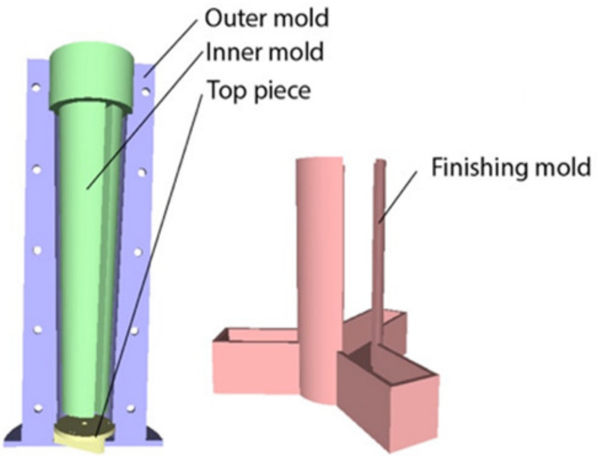


Fig. 1. The mold parts.

The modeling is done by parametric programming. This means that the dimensions of the tentacle mold can be altered (e.g. maximum- and minimum diameter, length etc.) simply by changing the variables listed at the top of the script (see Fig. 3).

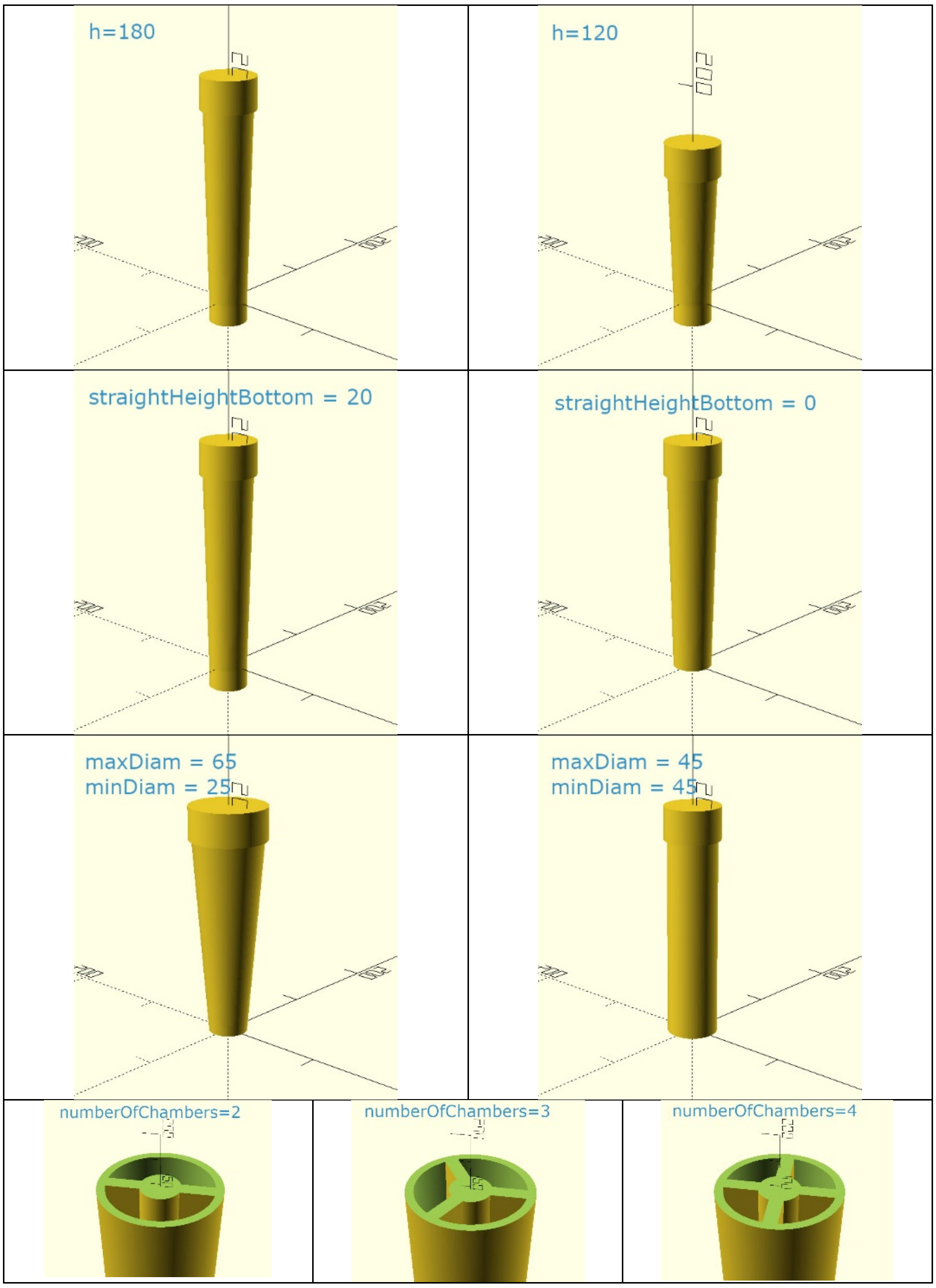


Fig. 2. CAD renderings of a tentacle with different values chosen for the main variables of the tool.

The main variables defining the tentacle morphology are illustrated above in Fig. 2. A working tentacle can be produced by just altering these. However, it is also possible to change other parameters including the interior solid radius, the wall thickness (interior and exterior separately), the mold assembly, and the mold stand.

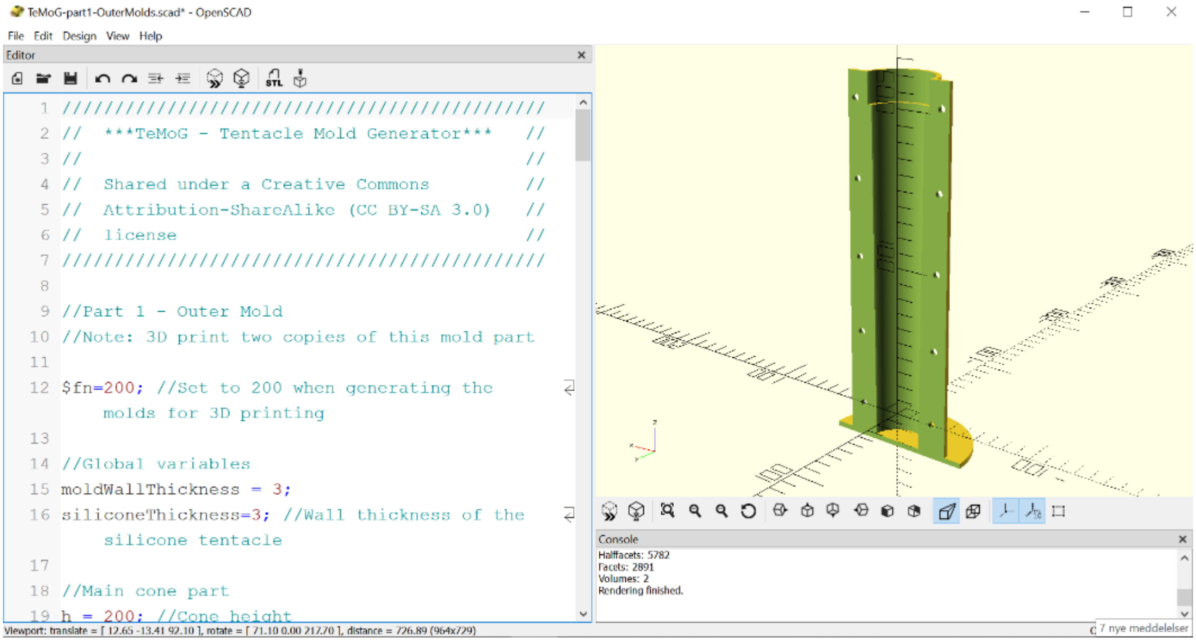


Fig. 3. Screenshot from OpenSCAD showing a CAD rendering of one of the sides of the outer mold.

Creating a mold

The mold parts are exported as STL files. These can be sliced in a 3D printing program and printed on a consumer grade 3D printer.

Generating an STL File

- Download and install OpenSCAD (http://www.openscad.org/downloads.html) on your computer
- Download and open the parametric parts files.
- Adjust the parameters to achieve the desired actuator morphology. Use "Preview" (under the "Design" menu) when you are altering the variables, to verify their effect on the design.
- Once you have the correct design, choose "Render" (under the "Design" menu) to generate the 3D model.
- Then choose: "File" -> "Export" -> "Export as STL" and save the file.

3D Printing the Mold

The mold parts can be printed in PLA or another rigid material.

- Import the STL file in the slicing software (e.g. Cura or Simplify3D). Orient the 3D model so that the bottom of the mold is oriented downwards.
- Before printing it can be helpful to also add a brim to prevent the mold from curling up at the corners or coming lose during printing. It is recommended to print in solid.

Fabrication of the tentacle

The fabrication process for a tentacle is shown below in Fig. 4, Fig. 5, and Fig. 6 with the *Phytomatonic 01* tentacle as an example (described under case studies further down). The production process is similar for tentacles used in the other examples, except that for some another "Top Piece" and the smaller "Finishing Mold" was used.

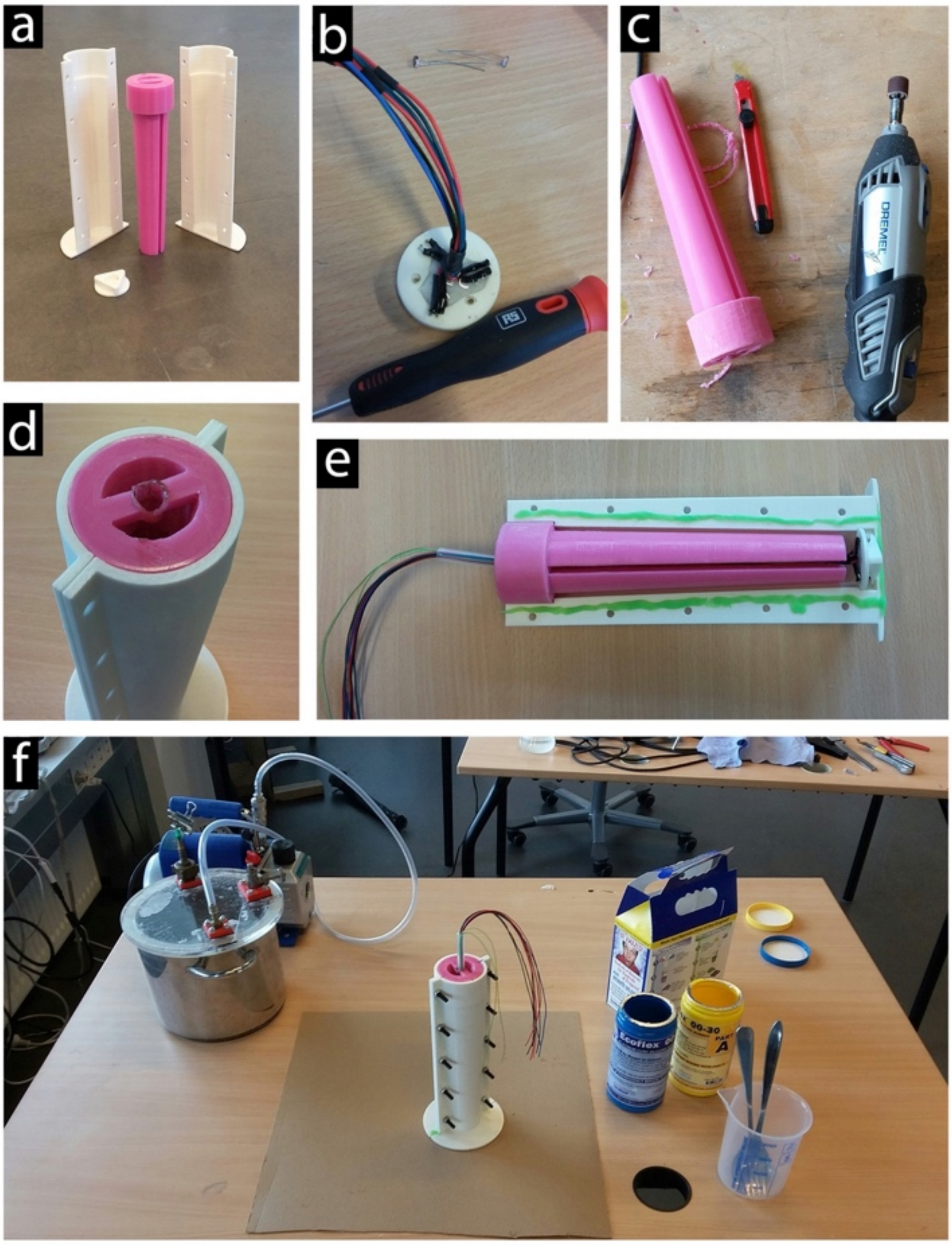


Fig. 4. Preparations for the casting.

Fig. 4 shows the pre-casting process. The outer mold and inner mold parts (a) were brushed with a thin layer of liquefied Vaseline (commercially available mold release agents can also be used). For

Phytomatonic 01, the "Top Piece" was fitted with three light-dependent resistors and wires and a layer of epoxy glue was added to attach the wires (b). Due to printer inaccuracies, some small corrections may need to be made with a Dremel tool and an x-acto knife for the mold parts to fit together snugly (c-d). In next step, a thin layer of (green) Play-Doh was applied to the edges of the mold to seal the contact zones between the two outer molds (to make sure the mold would not leak liquid silicone). It is important that the Play-Doh does not get into the mold itself, as it will inhibit curing and produce a soggy composite substance when combined with Ecoflex silicones (e). The mold is then closed by inserting the bolts in the holes of the outer mold parts and tightening the nuts. Finally, Ecoflex was mixed with silicone pigments and degassed in a vacuum chamber (f) to get rid of air bubbles (it is possible to cast the tentacle without degassing the silicone), before it was gently poured through the hole at the top of the inner mold and into the bottom of the "Finishing Mold" (Fig. 5a). After 24 hours of curing at room temperature the demolding and bonding of the bottom and top part of the tentacle can be performed as shown below in Fig. 5.

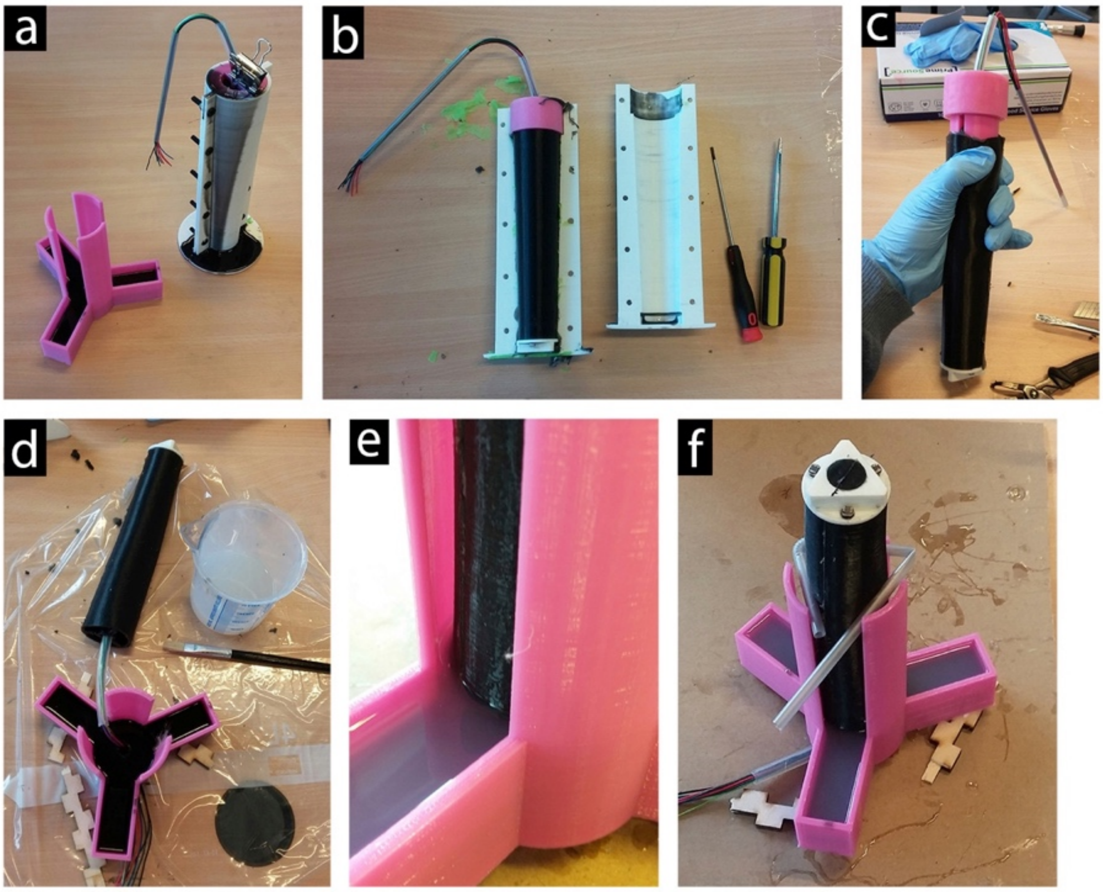


Fig. 5. Molding the tentacle.

The nuts are loosened, and two outer mold parts are pried apart gently using flat head screw drivers (b). The inner mold is pulled out of the tentacle by pulling and wriggling it so that it comes loose (c). Liquid Ecoflex is brushed on the contact surfaces between the tentacle and the bottom part that has been cast in the finishing mold (d). A layer of Ecoflex is poured into the finishing mold and the tentacle is placed standing upright in the finishing mold. A bit of air is pushed out of it so that some uncured Ecoflex is sucked inside it, to increase the surface area of bonding between the two (e-f).

After 24 hours, the tentacle is removed from the "Finishing mold" (Fig. 6a).

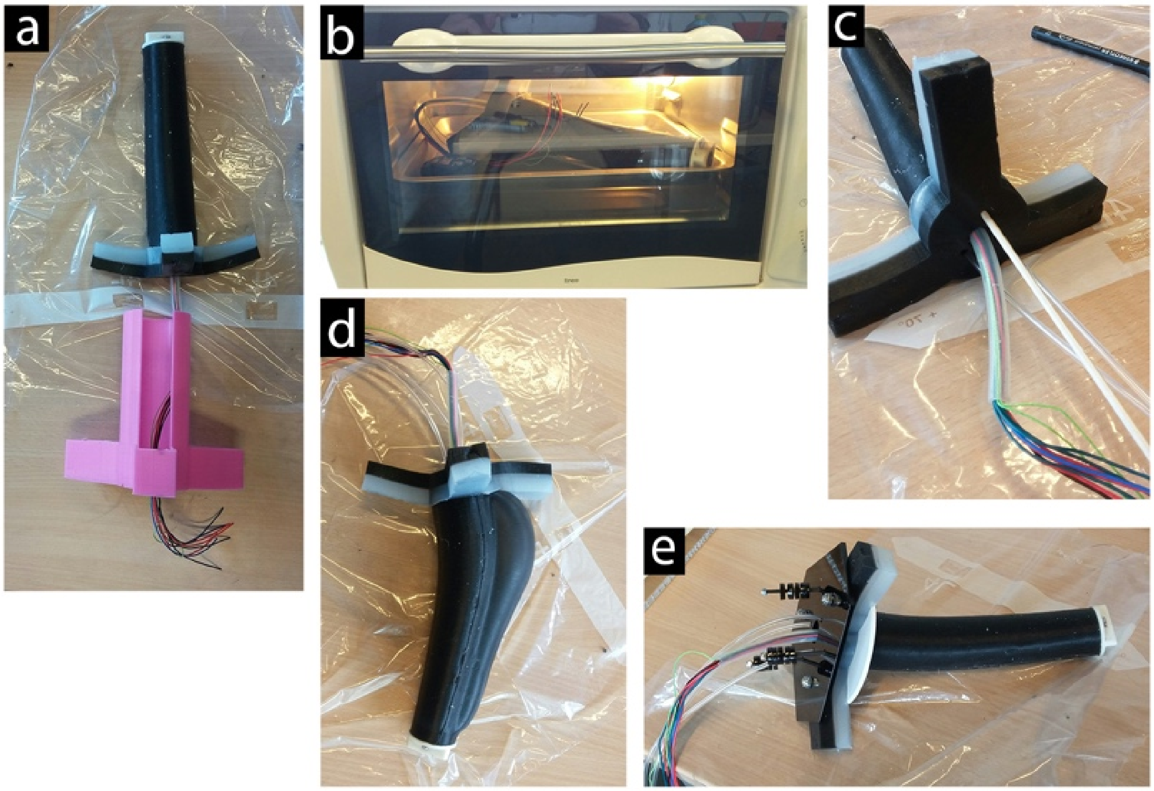


Fig. 6. Finishing the tentacle.

If the silicone at the contact surfaces between the bottom and top parts is not fully cured, the cast can be put in an oven at 75 degrees Celsius for about an hour (Fig. 6b) to finish the curing process. After this, holes are poked from the bottom into the three separate air chambers using a bamboo skewer (c) and PVC tubes are inserted into the holes. The tentacle is inflated to test that the three internal chambers are airtight (d) and the PVC tubes are then glued in place with Sil-Poxy silicone glue.

Fiber reinforcing the tentacle

For the “blue robot” used in the HRI experiment (see case studies below), fiber reinforcements were added to the tentacle to prevent radial expansion. This was done as described below.

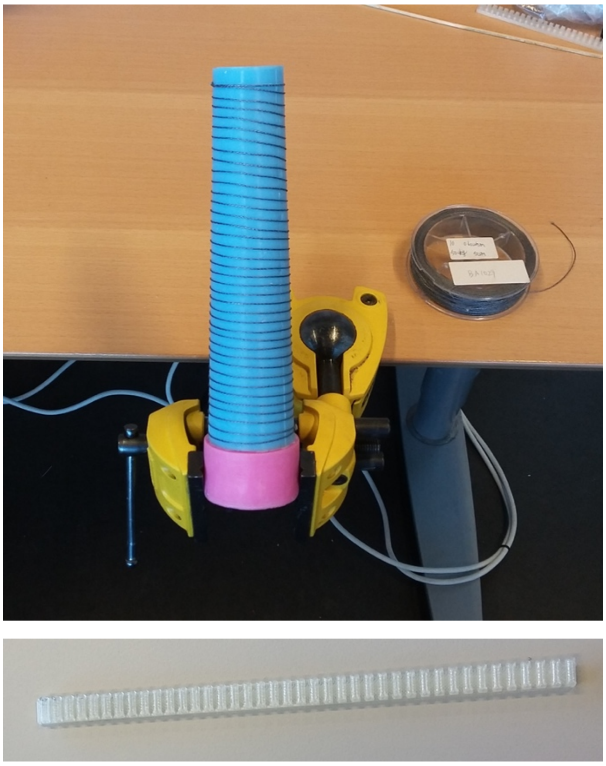


Fig. 7. After the tentacle with the inner mold has been removed from the outer mold, the end of the inner mold is fixed in a clamp. Braided fishing line (0.6mm, 50kg) is wrapped around the tentacle from the bottom. A 3D printed guide (included with the OpenSCAD files) with equidistant ridges (lower image) was used to position the windings with an equal distance to each other. The fishing line is then secured at the top with a knot and epoxy glue.

Fig. 8. The fishing line is wound around the tentacle from the top to the bottom in the opposite direction of before and fixed with a knot and epoxy glue at the bottom. The overlaps between the windings are aligned to be vertically parallel on opposite sides of the tentacle, and the distance between the windings adjusted with the 3D printed guide.

Fig. 9. Two mixing sticks and rubber bands are attached around the inner mold as shown, in order to lift the tentacle slightly to make room for an extra layer of silicone in the mold. The outer mold is filled with liquid Ecoflex up to about a third full and the tentacle and inner mold is inserted. This step can also be done with a second mold that is slightly larger, this way, an inactive top can be avoided.

Fig. 10. After 24 hours of curing, the tentacle can be removed from the mold and the bottom part and tubing can be attached.

Case studies

Molds created with the tool have been used for several soft robotics projects including those described in the paper. For inspiration we describe a couple of additional projects below.

Light seeking plant-inspired soft robot prototype

Phytomatonic is a series of speculative design prototypes that explore how soft silicone might afford an artificial agent other relations with biotic elements in an environment than rigid materials (Jørgensen 2017b).

The central element in the prototype *Phytomatonic 01* is a black soft robotic tentacle. It is equipped with three light-dependent resistors (LDRs) at its tip that allow it to detect incoming light. The prototype replicates characteristic aspects of a growing plant by means of soft robotics technology, namely its phototropic behavior and the mechanism by which directional change is accomplished through cell elongation on the shady side of the stem (triggered by an accumulation of the plant hormone Auxin).

The robotic part's mode of functioning thus echoes the working of the cress plants placed at its tip and the robot's light-seeking behavior evokes notions of a common desire for light shared by both the biological and technical part of the system.

Video: https://youtu.be/-awxAXI035E

Beyond Digital towards Biological

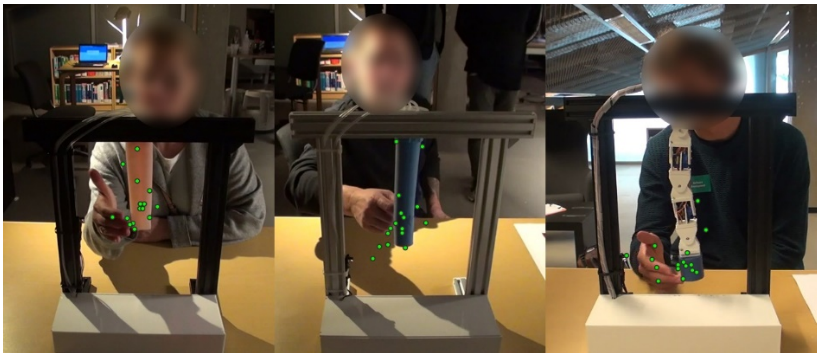
A translucent tentacle was featured in the *Beyond Digital towards Biological* art installation by Laura Beloff, Jonas Jørgensen, Stig Anton Nielsen, David Kadish, and Stavros Didakis exhibited at Chronus Art Center, Shanghai in 2017.

Video: https://youtu.be/UX3swR57zUo

More info: Beyond Digital – Towards Biological and http://i-dat.org/beyond-digital-towards-biological/

HRI experiment

A blue tentacle cast in a mold created with the tool was used for a human-robot interaction experiment (Jørgensen 2018; Jørgensen et al. (forthcoming)). The experiment sought to explore people's perceptions of soft robots and to identify differences in how people intuitively interact with a soft robot and a rigid robot.



Video: https://youtu.be/yidsot2PPpE

Preliminary results of interaction experiments have been published as a Late-Breaking Report (Jørgensen 2018a) and a video (Jørgensen 2018b).