Bioinspired Design: Aristotle's Lantern and Models of Rotational Geometry by Giorgio Scarpa

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1 Background

Giorgio Scarpa (1938-2012) taught Descriptive Geometry and Theory of Perception from 1960 to 2008, in Sardinia and later in Faenza, Italy. In the early 1970s he built a large, physical model of the masticatory apparatus of the sea urchin or Aristotle's lantern. The model appears in 1985 in *Modelli di bionica: capire la natura attraverso i modelli* [1], while his earlier book, *Modelli di geometria rotatoria* [2] on models of rotational geometry, dates from 1978. Although many morphological studies of Aristotle's lantern exist [3-4-5], until recently Scarpa's model was the only known, published physical model to offer direct manipulation and observation [6,7].

Scarpa's models of rotational geometry are also bioinspired, in particular by the movement of rotation found in nature. Here, articulated chains fold back into minimum spaces or transform into new shapes. Scarpa's models were made mostly with paper and glue but current prototyping techniques allow construction of new models, including some that were drawn but never built, such as chains connected together to form transformable 'fabrics'.

This article describes the process of building a functional replica of Scarpa's bionic model of Aristotle's lantern — the original model needs minor repairs — as well as some of his articulated chains.

2 Methods

Based on original drawings, 3D-printed parts were made to replicate the model. The real lantern "consists of 40 different ossicles forming a typical pentamerous framework" connected together by means of "bands or bundles of specialized ligaments" (Fig. 1A) [3]. Within five composite pyramidal jaws, five teeth move slowly downward during permanent growth but are firmly in place when feeding or boring through rock (Fig. 1BC) [8-9-10].

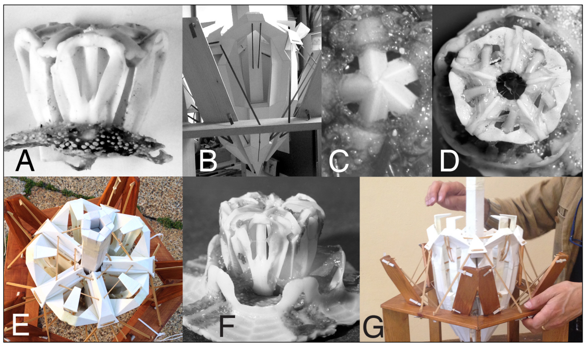

Figure 1. A: Lantern; B: Scarpa's original model; C: tips of teeth meeting at the oral base; D: top view of the aboral base; E: replica of model (2014); F: lantern attached to perignathic girdle and auricles; G: replica with elastics that keep the model in tension.

In contrast to the real sea urchin, when the jaws open in the model, the teeth quickly slide forward (Fig. 2). In real life these moving, 'loose' teeth would not be very strong, yet Scarpa's design neatly provides a kind of time-lapse image of the growth of the teeth during a lifetime — although continuous 'self-sharpening' of the tips accounts for their unchanging external appearance [11].

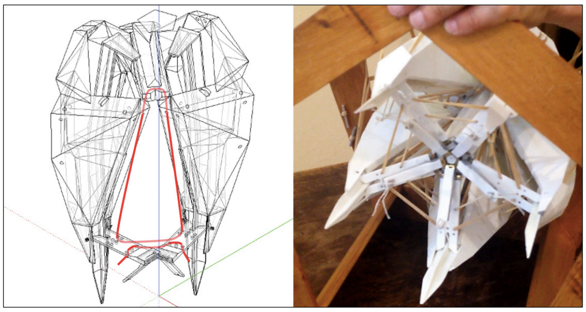

Figure 2. Left: Diagram of the path of one elastic ring going through two jaws, a rotula and two spokes. The vertical prism to which the spokes are attached is not shown. Right: the telescopic prism and spokes recall the design of a spring-loaded umbrella.

Five other ossicles, the rotulae (r), serve as joint-hinges between pairs of jaws and regulate downward translation of the lantern. Five more ossicles, the compasses (c), are positioned directly above the rotulae (Fig. 3) and also schematically reproduced in the model (Fig. 1E). The auricles, five protruding, angled ridges arranged internally around the edge of the perignathic girdle (PG) complete the set of 40 ossicles (Fig. 1F). The auricles are connected to the lantern's apex by sets of retractor muscles (RE) responsible for the opening of the jaws [3]. In the model, these ridges (auricles) are arranged at the corners of a pentagonal support frame.

There are "four sets of specialized muscles" in the lantern (Fig. 3) [3], represented in the model by thin, pure-rubber elastic bands connecting the parts together and anchoring them to the base (Fig. 1G).

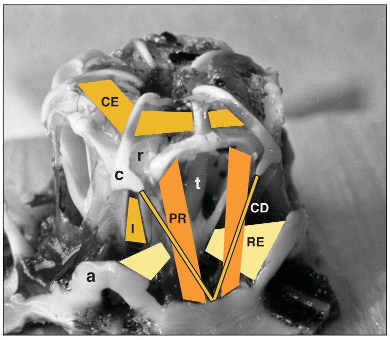

Figure 3. Diagram of the muscles and some ossicles. **CE** compass elevators; **PR** protractors; **RE** retractors; **CD** compass depressors; **I** interpyramidal muscles; **c** compass; **a** auricle; **r** rotula; **t** tooth.

1. Protractor muscles (PR) are responsible for protraction and lateral tilt. This set is absent in the model, where protraction is achieved by a telescopic prism and bridge mechanism. The same mechanism causes the teeth to slide forward (Fig. 2). 2. Retractors muscles (RE) allow opening of the lantern and lateral tilt. Elastic bands in the model connect each jaw to the supporting base. 3. Interpyramidal muscles (I) run between adjacent jaws and are responsible for closing the lantern. In the model, the sides of the jaws are connected by elastic rings, while another perimeter ring pulls the five jaws together to their rest position.

A third set of rings, connecting the jaws through the rotulae, then extending downward through each spoke responsible for the opening of the jaws, contribute to balance the forces within the system (Fig. 2). Compass elevator muscles (CE) connect and are responsible for raising the compasses (Fig. 3). In the model, two concentric rings connect the compasses. In addition, compass depressors (CD), part muscle — this part being responsible for lowering the compasses — and part ligament, connect the compasses to the perignathic girdle, contributing to the overall stability of the system [3-4-12]. In the model, elastics connect the ‘compasses’ to the base.

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For the printing of the articulated chains — the models of rotational geometry — two different materials were used for the modules and for the flexible hinges connecting them. The main difficulty here was how to best arrange the modules before printing, to shorten printing time while retaining the smoothness of the surfaces and the edges. As rapid prototyping allows for relatively fast production of different chain configurations, the process can be used to test the more elaborate designs that were left as concepts only. In his book, Scarpa places one such design next to a micro-photograph of a muscle fiber [2, pp. 94-95], hinting that “models of rotational geometry” could offer clues to biological mechanisms such as muscular contraction. Due to limited resources, it’s not currently possible to replicate all of his rotational models, but a draft English translation of both of Scarpa’s books is available online [13]. These can continue to be a source of inspiration for designers and engineers.

3 Results

Additive manufacturing allows the designer to quickly produce working prototypes of simple and complex models. However, a certain amount of finishing and assembly is often still required, especially if the prototyping equipment is limited and the component parts have to be printed separately, as was the case with the model of the sea urchin. On the other hand, where relatively simple shapes are involved, and where the connections consist of repeated elements of a second material that can be embedded into the first material during printing, minimal assembly is definitely an advantages of 3D-printing. Still, even with simple articulated chains, good modeling on the computer is essential for the success of the production process.

4 Interpretation

Scarpa’s work in bioinspired design is a largely untapped source of inspiration for the designer and the engineer. Recent applications — inspired and influenced by Scarpa’s model of the sea urchin — by a team of Dutch engineers led by Filip Jelínek who designed a new experimental prototype of biopsy harvester [14, 15], and an American team led by Michael Frank who designed a prototype for a mini Mars rover to improve soil collection [16], attest to his pioneering work. Replicas of Scarpa’s models provide a deeper understanding in addition to photographs. Many of his experiments and physical models have not been published yet but in the future they will no doubt provide an additional source of interest and inspire design innovations in those willing to explore his creative path.

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