Component Design
An Evolutionary Process

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The design of the components, assemblies, and actuated devices of the Hylozoic series is an evolutionary process. Each specific device and each constituent component is developed incrementally, refined and specialized. Components develop in response to constraints that push their design towards strength, lightness, simplicity and expression. This iterative process improves the structure in specific ways—strengthening a local weakness, preventing a joint from cracking, or increasing range of motion. Initial production tends to focus on the component itself, clarifying and refining its individual qualities. The interface between an individual component and other devices is addressed in further cycles. Understanding how a component functions in its larger context—at the level of the assembled devices, or integrated system of which it is member, and within the environment as a whole—is fundamental to the component design. For example, comprehensive physical stresses involving torsion and strain tend to appear only after complete assembly, as the weight of the entire environment is
balanced and distributed. Similarly, long term mechanical movement and cycling of integrated systems reveal unanticipated stresses on specific components.

The cycles of analysis, hypothesis, testing, and evaluation tends to produce a surplus, a plethora of offspring that remain as incomplete sketches, half-built joints, and preliminary test assemblies. As with biological evolution, general families of parts evolve in parallel, and are differentiated by incremental changes in geometry, connection, and utility. Changes in one component often affect changes in others and may speed up development, as lessons learned while working on one component can be applied to another in its family, like a kind of heredity. On the other hand, this process may cause a development lineage to be aborted because it has become obsolete.

component design

Acrylic, copolyester, and silicone—resilient, flexible, and self-supporting materials—are used to manufacture the bulk of components in the Hylozoic environments. The most commonly used material is sign-grade impact resistant (IR) acrylic. Resistant to distributed bending stress, IR acrylic is free of ‘grain’ or directionally-biased stiffness. IR acrylic is used for the chevrons that make up the Hylozoic diagrid meshwork and the skeletons of most Hylozoic assemblies and devices. The transparency of the hard IR acrylic is preserved by the particular laser-cutting process used in the studio, which polishes the edges of the plastic.

Localized or point stress can cause cracking and failure in the acrylic. To take advantage of its strengths and prevent weaknesses from manifesting, a number of features have been developed including snap-fit joints, crack-stop corners, and gussets. Copolyester is more flexible than IR acrylic, with increased resistance to cracking and corner stresses, but at the cost of a somewhat cloudy appearance. These qualities make copolyester suitable for hinges and flexible ribbons seen in the ‘tongue’ cores of the sensor lashes and breathing pores.

Cartilage-like layers of silicone appear throughout the Hylozoic environment. Silicone is extremely flexible and elastic, and is employed in pre-manufactured tubes cut by mechanical means. Silicone’s increased flexibility
makes it ideal for use in flexible joints and vibration dampeners for motors. In combination with snap-fit junctions, these layers are employed in areas receiving additional stress, including densely-massed systems of interlinking joints in the filter layers, demountable access vents within meshwork columns, and force-relieving gussets for the meshwork canopies.

Specialized snap-fit acrylic joints are predominantly used for joining mechanisms required by the Hylozoic meshwork, assemblies, and devices. Snap-fit joints are common in industrial and product design where they appear in such forms as the lip of a felt tip pen, or the snaps on vacuum-formed retail packaging. A standardized joint recurs within the system. This joint, which has undergone many iterations and stages of refinement, is used to connect two laser-cut acrylic components axially, tangentially, or in parallel. IR acrylic has proven to be effective and reliable for manufacturing the snap-fit joints, and requires no other mechanical fasteners or adhesives. The length and thickness of the jaws and size of the ridges can be varied to produce loose, temporary connections or tougher, more permanent joints. While the flexibility and hardness of IR acrylic make it an excellent choice for snap-fit joints and bendable hinges, the flexural stresses on the material tend to concentrate at sharp corners, leading to cracking and failure. Crack-stop detailing involves filleting or rounding off the interior angles to distribute the stress over a greater area. The amount of filleting or easing that is required is often fairly small relative to the size of the component. In some cases, the easing can be pushed into an internal cavity in the component. This approach is often used when the U-shaped crotch of a part needs to provide a positive stop to secure and limit the movement of another part. Crack-stop corner detailing is employed in a variety of components, including latching clips employed to secure air muscles in swallowing columns, tightly-fitted voids for modular jacks in actuated devices, and buckle fasteners for securing whisker sensors.

Joints, corners, and nodes can be strengthened by thickening as a way to re-direct stress to adjacent areas. Conversely, removing material from the edges of a part will weaken it or make it more flexible. In combination, these strategies can be used to focus bending to a particular area of a part and create a hinge. Creating smooth transitions between thinned and thickened sections prevents stress build-up and subsequent cracking. Creating a void in the interior of a component is a way to reduce the weight of a part while
breathing pore evolution

1 Breathing pore feather  2 Tongue  3 Strengthening gusset for main spine  4 Tongue stabilizer  5 Shape memory alloy fin
6 Arm unit  7 Tongue lash  8 Gland clip  9 Strut clips  10 Lever stop  11 Main spine  12 Lever  13 Tongue strut
14 Tongue end strut  15 Attachment to mesh
maintaining strength. Refinement based on particular strategies of thickening and voiding has been applied to the chevron family of components, permitting these elements to handle substantial torsion forces.

While a combination of thickening and voiding can be used to add strength without increasing weight, these strategies are limited to two-dimensional orientations.\(^6\) Third-dimension stiffness is often achieved with flanges, which are added locally for reinforcement. These are also attached along the entire length of a part to create T-shaped beams, as in the example of the breathing pore spine.\(^7\)

The manufacturing stage is fundamental to the advancement of component design. Arrayed components are reconciled with the rectangular dimensions of a sheet of IR acrylic scaled to fit in the cutting bed of a CNC (Computer Numerical Control) laser cutter. The organization of the array prior to cutting can add another variable to component design, especially for components that will be produced in greater numbers. In order to use materials efficiently and reduce waste, the shape of the component is refined so that it fits a tightly as possible with duplicates and other components on the same sheet. In the case of the chevrons that make up the expansive mesh lattice, the tessellation of the component has been refined to the point where they are fully nested and share edges. Sharing edges makes it possible to remove overlapping lines, greatly reducing cutting time and reducing material waste to nearly zero.\(^8\)

IR acrylic responds well to laser cutting, which produces smooth, clear edges. The heat of the laser tends to vaporize the upper surface to a greater degree than the lower, creating V-shaped cuts and bevelled edges. The greater the thickness of acrylic, the more power is required to cut through the material, resulting in more pronounced sloping of the cut edges. Tuning both snap-fit and simpler, slotted joints becomes increasingly difficult in components cut from the thickest acrylic, since the diameter of a slot at the upper edge may be significantly wider than at the lower edge. Given this eccentricity of laser cut pieces, thinner IR acrylic stock material is selected wherever possible; this has the added benefit of also reducing weight and cutting time.
kinetics and actuated devices

Hylozoic Ground includes a large number of actuated, kinetic components including the filter layer, swallowing actuators, sensor lashes, and breathing pores. The iterative refinement process has proven critical to the development of the actuated devices in achieving both efficiency and physical and conceptual integration into the Hylozoic environment.

Several actuation mechanisms have been explored at various points during the design development. Of the many different solutions available, the silent, subtle motions produced by shape memory alloy (SMA) wire support its primacy among materials used in Hylozoic Ground. Flexinol (a trade name for the nickel-titanium alloy material) has a crystalline structure that can be stretched mechanically when cool, and can then be reset to its original, shorter length by applying heat via electrical current. The high strength of the wire in its hot state means that it can exert a sizeable amount of force when it contracts. The amount of force exerted and current required are proportional to the thickness of the wire. Initial development in the Hylozoic series employed thin (0.004”) wire, keeping power consumption to a minimum. More recently, thicker-diameter (0.012”) wire has been used for its increased strength and durability. To balance the increased power demands of the thicker wire, behaviour patterns to organize and limit the number of SMA wires that are activated at any time have been explored.

Flexinol’s response to electrical current is silent. The contraction of the wire is characterized by a logarithmic envelope response pattern, similar to the natural movements of muscle fibres in living organisms. An individual wire will only contract by about five percent, inviting the use of amplifying levers layered with tendon and pulley systems to create visible motion. Mechanical linkage systems have proven to be an effective way to balance degree of movement with strength.

The Hylozoic filter layer employs clusters of devices that contain rigid structural skeletons, containing long, extended arms that have been thinned to create a hinge point. SMA wire is installed just above this hinge point to effect the greatest motion at the top of the tapering arms where the filters are attached. Successive generations of these devices have pursued increased motion, focusing on hinge and arm profiles. The hinge design
attempts to strike a balance: being supple enough to allow the SMA to express its potential, while stiff enough to fully stretch out the SMA in its cooling phase. Laser cut mylar fronds are mounted at the top of the long arms. Folds created by laser-scoring the mylar were designed to give stiffness, and to accent and focus the movement.

The actuated devices referred to as breathing pores and sensor lashes achieve dynamic motion in a more complex way than the actuated devices in the filter layer. The core assembly of these devices is a flexible acrylic and copolyester tongue. A long tendon of high-strength nylon filament is used to pull on the tip of the tongue. The tendon is then attached to the tongue at specific intervals to compound the relative movement of the tendon. Design iterations have lead to a tighter spacing of filament guides, calibrated to the material’s tendency to form a local hinge point. With tighter spacing, the interior of the tongue could be voided to reduce the pull force required. This was instrumental, as it allowed the tendon to be placed closer to the tongue, thereby creating a dramatic increase in movement with less total tendon pull, but with the pull force still kept in check. The relationship that formed, whereby more pull force and movement could be achieved with reduced energy input, made for an effective marriage of these components with SMA wire actuators.

Designing the swallowing actuators presented a different sort of challenge. Generating enough force to move the strong structural grid over a large distance had to be balanced against maximizing the effect of the motion. To address this, the swallowing columns have undergone three major changes within the Hylozoic series.

The first series of swallowing actuators employed a paired linking mechanism in the form of a scissor-type jack.\(^9\) When the initial triangle of the jack can be turned to reach wide, obtuse angles, contraction along its hypotenuse will produce the greatest increase in the distance between this vertex and the hypotenuse, and thereby create the greatest effect. Predictably, this effect comes at the expense of additional required pull force. This also requires a long apparatus compared to the effective length of the device. To increase pull force to the levels necessary to distort the three-dimensional structural grid, three SMA wires were used in tandem to operate a rigid triaxial linkage reaching out to points around the perimeter of the inner column.
walls. To increase their reach and strength, the segments of the linkage were thickened through their middle sections, and gusseted. Threaded fasteners were used to connect the segments, creating hinge points at the vertices of the linkage. Relatively complex, time-consuming part assemblies resulted from this approach.

A second version of the swallowing actuator was grafted onto the inside surface of the column, operating in isolation to locally deform sections of the column grid. A mechanism similar to the first version was used, though the way in which its elements were distributed and operated was inverted: The SMA moved from the hypotenuse to replace the two formerly rigid segments’ triangular linkage, while the hypotenuse transformed into the structural backbone of the device. This structural rib was doubled up, stiffened, and shaped to follow the curvature of the column and provide clearance for the rod assembly. The SMA is housed between the two ribs and rolls around wire pulleys at the vertices of the linkage, allowing many fasteners and pivot points required in the earlier version to be eliminated entirely. These pulleys also allow the SMA actuator to be lengthened and folded back on itself to increase the total amount of contraction.

Using obtuse-angle geometry to maximize the SMA contraction as before, the force is in turn directed to the column walls by a wire rod guided by a plate spanning the ribs. To allow the wire rod to withstand the heat of the SMA actuator, a part was digitally modelled and manufactured in ABS plastic using 3D printing technology. This part fits onto the end of the wire rod and accepts a small metal ferrule that can handle the heat given off by the SMA as it contracts under current. Digitally modelled and printed elements like this allow for complex connections and relationships to be greatly simplified.

In the current iteration of the swallowing column, miniature banks of SMA-powered pneumatic valves are used to control air pressure in rows of ring-shaped custom air muscles, coordinating their action to produce a peristaltic motion in the surrounding meshwork. Fixed-length interwoven polypropylene jackets restrain the inflated dimensions of the muscles’ latex core. Increased diameter forced by the distended latex results in shortening of the muscle. The silent action of these SMA valves offers a subtle envelope of response, similar to the organic movement implied by muscle wire-actuated kinetic devices within the environment.
Refinements in the swallowing actuator have prompted parallel experiments aimed at creating flexible axes within the diagrid mesh structure without undermining its integrity. Variants in the design of the chevron components, and the use of silicone tubing to create flexible connections at particular points within the matrix, have increased the performance of the diagrid meshwork. These changes have also reduced the pressures on devices and the actuators, increasing the integration of kinetic devices within the fabric of the Hylozoic environment while still permitting wide deformations and a highly varied topology.