Expansions and Imperfections

Experiments on a Self-Morphing Lattice

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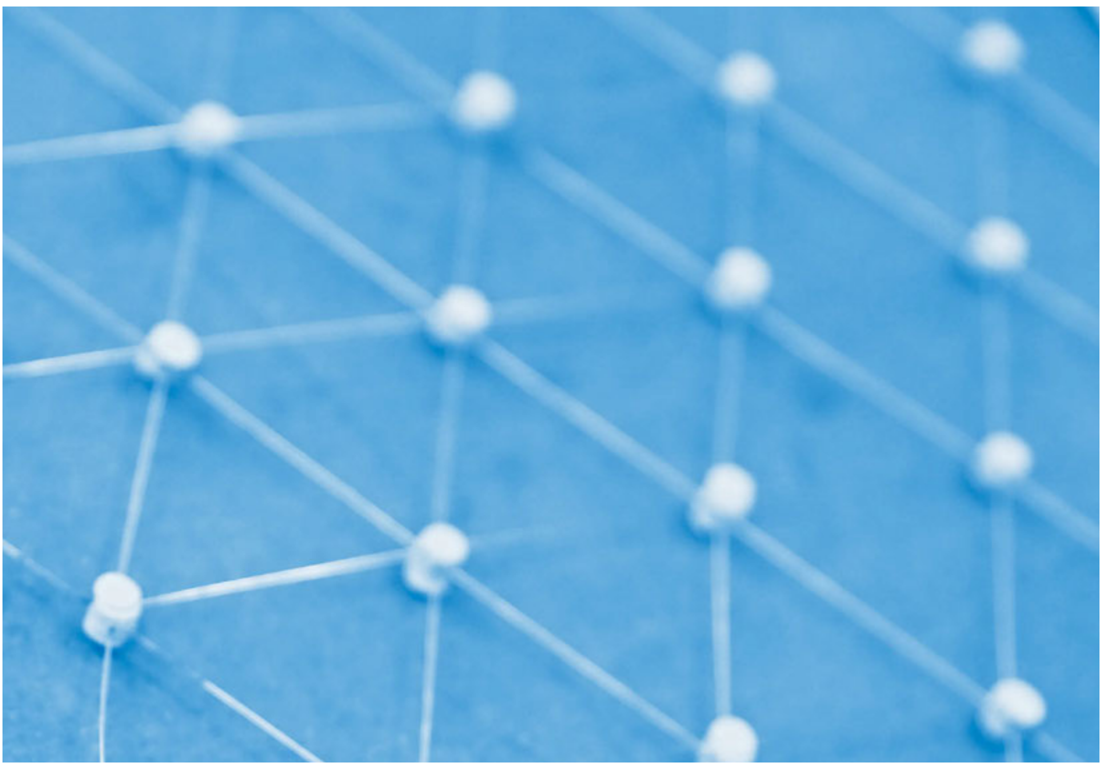


Selma Lepart (SL) and Lorenzo Guiducci (LG): In 2018 we participated in two workshops—"Behavioral Objects/Behavioral Matter,"[1] and "Behavioral Matter,"[2] centered around the concept of behavior as applied to objects and materials. This is where our collaboration began, melding the tradition of working through practice of the artistic community with notions, methods and tools more typical of the scientific and engineering fields, thus stimulating new research questions.

LG: As a material scientist, I am interested in the mechanical actuation of biological materials which allows dead plant tissues without muscular capacity to generate forces and movements. A typical example is the spontaneous opening and closing of pine cones, caused by differential expansions upon changes in environmental humidity.[3] Inspired by such autonomous actuation, I built a morphing structure based on a flat triangular lattice assembled from plastic connectors and steel wires (fig. 1). An increase in the length of these wires creates an internal compression, which in turn forces the structure to deform from a flat to a three-dimensional shape. The starting point of this investigation was scientific: I sought to understand how the morphing behavior of the lattice depends on its geometry and on the mechanical properties of its components. Revealing this structure-function relationship would allow for the programming of complex shapes by simply acting on the wires (fig. 2) and in turn lead to applications such as tangible user interfaces or soft robotics.

Presented at the workshop "Behavioral Objects/Behavioral Matter" the lattice was well received for the wide range of movements and shape transformations that it could undergo. Small length changes of the wires resulted in quite a large variety of obtained shapes.

SL: From my artist's perspective, I am interested in the agentivity of objects. What makes us think that they are endowed with a relational capacity, a sensitive intelligence, even a consciousness? I am particularly interested in the possibility of creating "nonliving entities" that contain no organic or biological material. I started engaging with the expressive

1 "Behavioral Objects/ Behavioral Matter," a workshop organized by EnsadLab, Paris, May 16–18, 2018.

2 "Behavioral Matter," a workshop organized by EnsadLab, ENSCI-Les Ateliers, (Paris) and the Cluster of Excellence »Matters of Activity« (HU-Berlin), November 21–23, 2018.

3 Dawson, Colin, Julian FV Vincent, and Anne-Marie Rocca. "How Pine Cones Open," *Nature* 390, no. 6661 (1997): 668.

capacity of the lattice, questioning to which extent life-like traits could be reproduced in a nonorganic object, and pushing us to contemplate the emotional relationship between the observer and the observed object. Acting on the wires with our hands revealed how unpredictable the morphing was: the lattice did not always follow the script. It showed small variations that seemed to be the result of its own behavior.

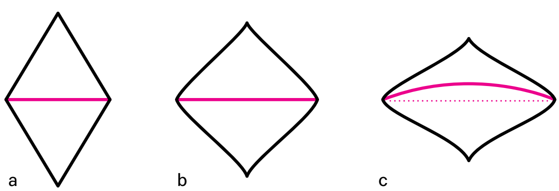
LG & SL: During the workshop we pursued these questions from our complementary perspectives. We connected the lattice wires to electric motors and flex sensors, making it an autonomous moving object (fig. 3). Bending the sensors would activate the motors, change the wire length and, in turn, deform the lattice: hence a responsive behavior (a reaction caused by an external stimulus) was obtained. By attaching the flex sensors on the lattice, a closed loop configuration was achieved: if perturbed from the outside, the lattice could "sense" its deformed state and the motors would respond by compensating with an opposite movement. At times, this resulted in a self-determined motion reminiscent of a "homeostatic" state—a dynamic equilibrium in which opposite reactions maintain a constant internal state variable (such as temperature in the human body) rather than an absence of reactions. These highlighted how these properties—responsiveness and homeostasis—are crucial in any living form and were indeed artificially reproduced (or at least metaphorically represented) with very little technological means.

We realized how the quality of these autonomous movements creates a strange feeling of empathy in the observer, who can interpret them as excitement, hysteria or an attempt to avoid pain (fig. 4). Either way, the objective reality of a scientific experiment (a prototype built to study morphing capacity in slender structures) met with the subjective experience of an artistic exploration. We let the observer think that this object was capable of having intentions of its own. Its regular geometric structure is far from being anthropomorphic or zoomorphic, its artificial origin is not hidden. Simply, a dynamic process occurs between the object and the observer, an atavistic instinct that makes us focus on a moving object, almost as it were demanding our attention. Our human cognition seems to fill a certain gap and enriches an artifact with a notion of interiority that it does not possess. The following report retraces the different phases of our work and raises questions from our respective disciplinary fields, which we either addressed individually or collectively.

Geometric and Manufacturing Principles of the Triangular Lattice

LG: In my research as a materials scientist, I explore different principles to design morphing structures and materials. I take inspiration from plants' seed capsules—which spontaneously deform upon swelling—and the field of mechanical metamaterials, in which structural instabilities are exploited to enrich and program the properties of a material. In this context, I built a flat triangular lattice that leverages the buckling of individual beams to obtain controllable morphing. When a slender beam (such as spaghetti) is under compression it loses its straight shape and bends. This phenomenon is called buckling, an unstable response of an elastic structure which, in order to escape a heavy load, exploits an alternative "softer" deformation mode. In the triangular lattice shown here, such buckling response is introduced by geometric construction: in the rhomboidal unit cell (fig. 1a), an expanding beam (in magenta) is under compression due to the constraint of the black beams; at low expansion (fig. 1b), the active beam is straight and the structure is still flat; at high expansion (fig. 1c), the compressive force on the active beam exceeds its critical buckling threshold: the beam bends out of the lattice plane and induces a slight out-of-plane bending of the rhombus, which will propagate to the neighboring rhombi, causing global morphing.

The lattice has a fixed rhomboidal framework made of steel wires glued to 3D-printed plastic connectors (fig. 1d). Additional wires are introduced through holes in the plastic connectors (fig. 1e): by pushing these free wires into the structure, an overall deformation of the lattice is obtained.



Figs. 1a, 1b, 1c: Geometric construction of the triangular lattice.

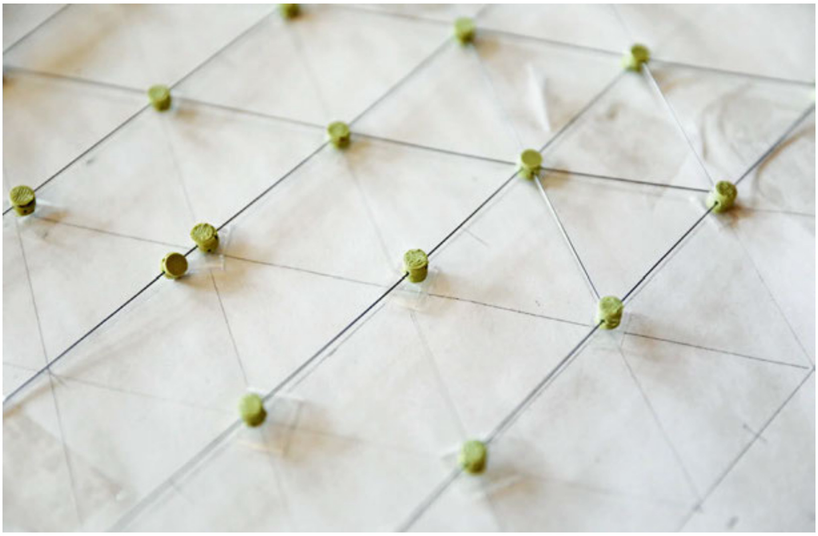


Fig. 1d (top): Fabrication of the triangular lattice (detail).

Fig. 1e (bottom): Connecting the lattice nodes with steel wire.

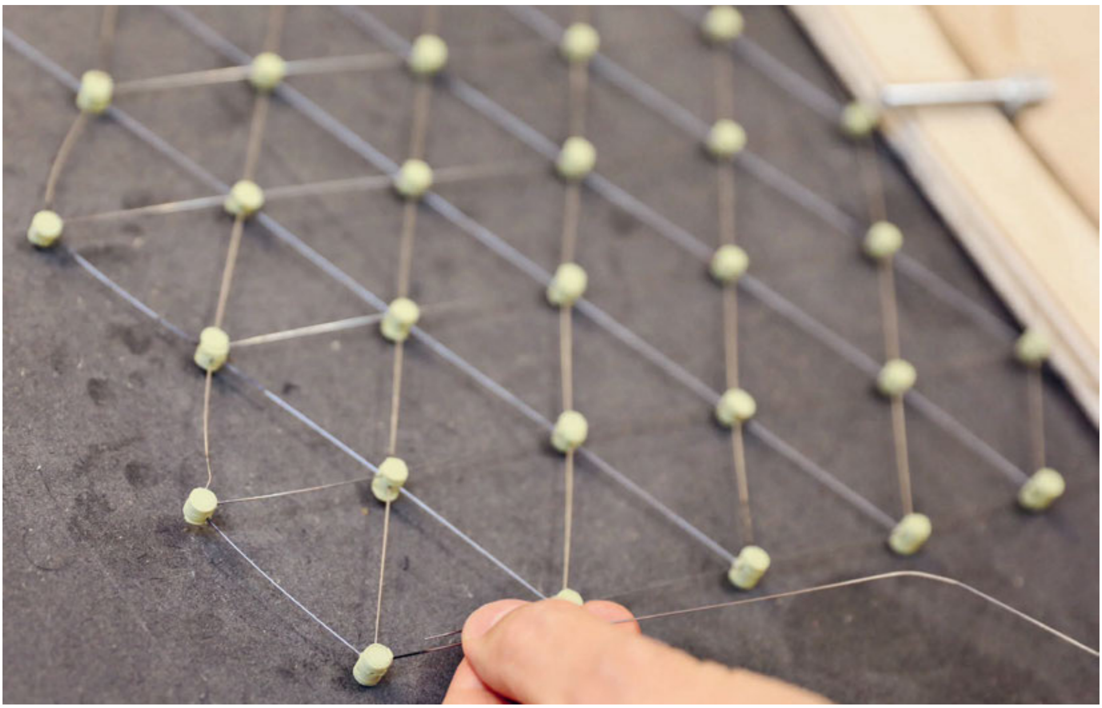
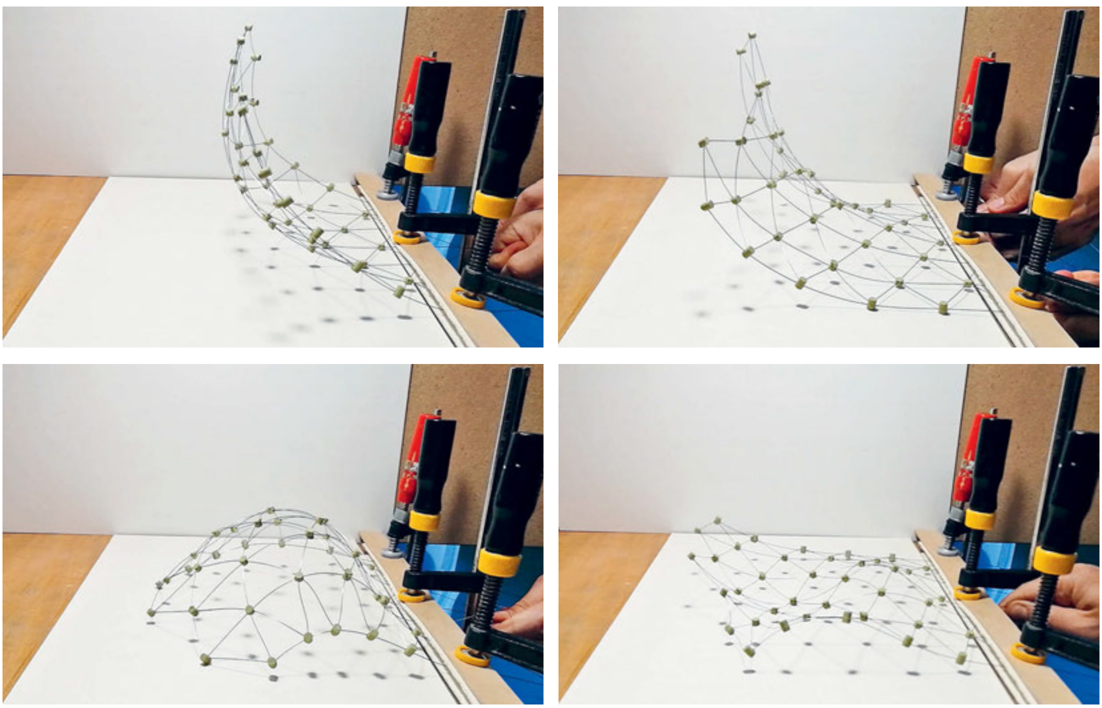


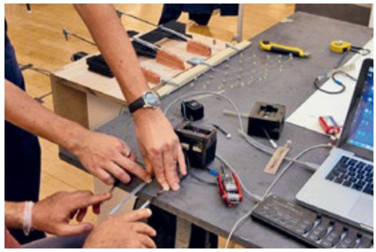
Fig. 2: Activating the lattice.

Morphing Capabilities: Is the Shape Predetermined or Emergent?

LG: The buckling of individual beams can be quite easily related to how much wire is fed into the lattice. Yet relating these local buckling events to the actual global deformation of the lattice proved to be more difficult. This is in part due to the many manufacturing imperfections—nonplanarity of the lattice, wires that are not perfectly straight, slight asynchronies in the activation of different wires—which, added up, lead to nonrepeatable movements (fig. 2).

SL: The lattice, held and stabilized on a table by a wooden slat and clamps, is not really thick, its shape is as minimal as possible. Our glance crosses it with ease. It does not hide anything of its composition. The plastic connectors are 3D-printed and the steel wires are chosen for their thickness, resistance, and flexibility. One recognizes the human touch in this geometrically regular arrangement of materials. Yet one cannot help but find a certain organic elegance in the changing shape of the lattice. All the manufacturing imperfections of the lattice create a choreographic richness and a sense of unpredictability. The lattice escapes our efforts of imposing certain forms while different ones emerge. Our attention is triggered by such contrast: a geometrically regular and clearly artificial object which is showing a behavior of its own, almost as a living being.





Animating the Lattice

Fig. 3a (right): Motors and flex sensors are connected to the steel wires of the lattice.

Fig. 3b (left): Controlling the movements of the structure with flex sensors.

LG: With the aim of better controlling the lattice morphing, we attached three motors to as many wires, thus replacing the human hand in this push-and-pull action. We also placed two flex sensors on the steel wires of the structure which would allow us to indicate to the motors the spatial configuration of the lattice (fig. 3a). During some initial tests we used the flex sensors as the keys of a piano to control its movements (fig. 3b).

Playing with this idea of a seemingly living yet inanimate object, we established a feedback loop between the flex sensors and the motors. The logical program (implemented in MisBKIT, courtesy of EnsadLab) simply consists of a narrow range of admissible values of the flex sensor signal: if the lattice (and hence the flex sensors) bends excessively, the motors move the wires back to reacquire the lattice reference configuration. Yet in this reaction the whole structure moves, always placing one zone or another close to the limits that have been imposed on it. As a result, the lattice is perpetually trying to rebalance itself. It is stuck in this feedback loop. We could see this attempt as an artificial reproduction of responsive behavior. Thus, we have recreated, albeit in a very rudimentary way, one of the most fundamental control mechanisms of life: homeostasis. The resulting movement is autonomous and not random. It is specific to this prototype and would not apply in any case to another, because it is in fact as if preprogrammed in the structure itself.

Fig. 4: Autonomous motion of the animated lattice.

Motion and Perception of the Lattice in Its Homeostatic State

SL: Equipped with motors, the lattice becomes a self-performing object. The structure and chosen materials play an active role in its capacity to move and to give the illusion of a behavior (fig. 4). A dialogue between form and movement is established and enters into resonance, revealing the behavior of the object. Shape and movement control, in a way, the course of events. These movements create a strange feeling of interiority. The lattice seems to improvise a choreographic score. The observer can almost recognize a form of primitive dance in its frenetic agitation. As if it could not bear its own condition, the lattice rises, frantically hits the ground, deforms and convulses to the limits of its physical body.

As if trapped, it is forced to the ground, firmly held by the piece of wood. It cannot escape, seemingly demanding attention and communicating a state of discomfort that can be interpreted as an attempt to avoid pain. With very little programming and outside intervention, the structural properties of the lattice (which link deformations and amplify movements) induce a strange feeling of empathy. As spectators of its struggle, we would almost like to see this thin metallic framework “escape its condition” as an object. We achieved excellent expressive results with minimal aesthetic and technical intervention.

Toward an Emotional Attachment?

SL: Our emotional attachment is focused on this lattice, which is neither anthropomorphic nor zoomorphic. This shows that it is not necessary to hide the artificial nature of an object in order to obtain "patterns" for the behavior of living beings. Perhaps this is due to a phenomenon of abstract pareidolia. As a viewer, we cannot inscribe our interpretation of the situation in a binary logic. Ours is much more complex, loaded with a referential acquired over thousands of years. In a way, we are the ones who confer this ability to be alive. We know that this object has no intentions. It is not even aware of its own presence. It does not know what it looks like. It does not know its position in space. It is not aware of the presence of a floor that it nevertheless hits frantically and with a rhythm that produces a certain musicality to our ears. It is not aware of our presence nor of the effect it produces on us.

The lattice exposes and stages itself in a dynamic process between object and public, making us believe that if an object moves, it is potentially animated by the same forces that animate us (fig. 5). The forces at work are not invisible. The three motors pulling the strings seem to be able to control it and play with it, producing the effect of a kind of mistreatment enacted upon this treatment to this object. However, the motors obey only the lattice. This relationship of domination by force that we seem to perceive is false. The motors do provide the power, but it is the lattice, in all its transparency and lightness, that controls the movements.

Fig. 5: Programming the morphing of the lattice.

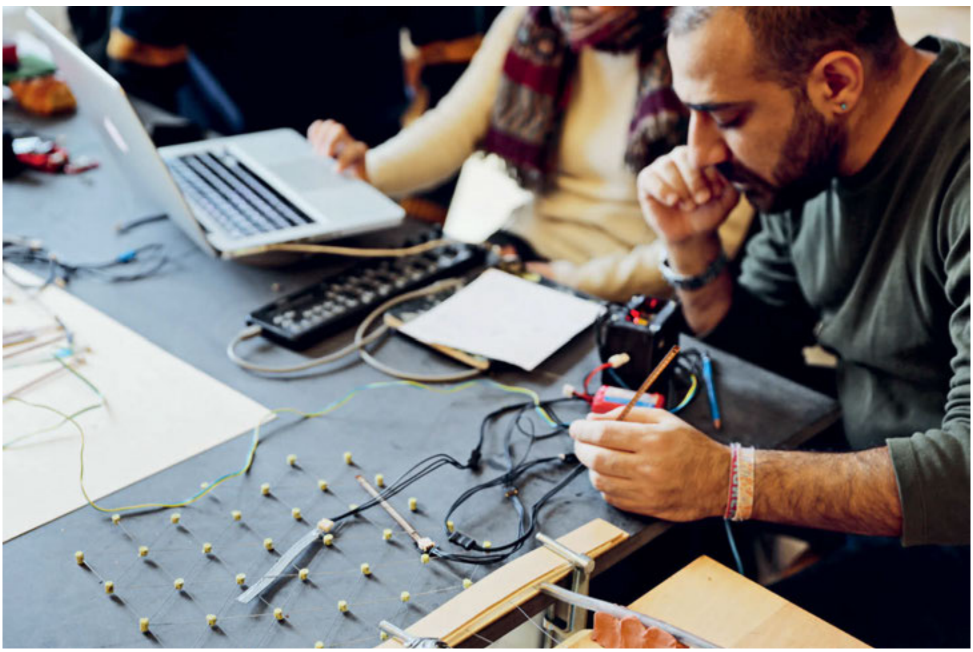


Fig. 6: Selma Lepart and Lorenzo Guiducci working together. Workshop "Behavioral Matter," Paris, ENSCI-Les Ateliers, 2018.

Assessing the Collaboration: Results, Impressions and Further Questions

LG: From a scientific point of view, programming the morphing of a triangular lattice requires further experiments: we still need to understand how the local buckling of the steel wires influences the lattice's global morphing.

SL: From an artistic perspective, further experiments could allow the lattice to exhibit new "behaviors" that we haven't observed yet. How far can we go into stripping away the motors, sensors, and components and still maintain an emotional connection to it? It's hard to help but find the object slightly dysfunctional. But dysfunctional in relation to what? We don't really know. It remains an impression, since the lattice was built for the specific purpose of being an object of scientific study and not to have any other function or utility. But even if we call it an "object" for lack of a better word to designate this "autonomous nonbeing," it is not really one. Must it become useful or functional to have the right to "a form of existence"?

LG & SL: In retrospect, we understand this overall process as a dialogue, a two-way making process (fig. 6). From the scientist to the artist, from the subject to the object (and vice versa). From the design and fabrication of the lattice, in which we give, prescribe, impose form, to the stage in which we observe the same object self-generating form, through spontaneous movements.

In this process, form generation and emergence drove different research questions. Today the main paradigm of scientific research in metamaterials is to program behavior onto a material, that is, to control it. Our collaboration shows that careful (and maybe even empathic?) observation allows us to discover new behaviors and properties that were neither really expected, nor useful per se. We argue that moving away from the question of function could lead to new applications in engineering and new questions in applied artistic research.