Prolegomena for a Transdisciplinary Investigation Into the Materialities of Soft Systems

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Abstract

This paper presents exploratory research on the materiality, aesthetics and ecological potential of soft robots. Within the still emergent paradigm of soft robotics research, bio-inspiration is often hailed as being of central importance. The paper argues that soft robotics should equally be seen as giving prominence to materiality and the enactive and processual potential of soft matter. The paper excavates different notions of materiality within media art that uses soft robots and in technical soft robotics research practices and discourses. Against this background, the author's own practice-based experiments with soft robots are presented.

Keywords

Soft robotics, soft robots, robotic art, bio-inspiration, materiality, ecology

Introduction

The field of soft robotics has in the past ten years become established as an emerging subfield of technical robotics research. A number of different definitions of soft robots exist but in general "soft" is taken to refer to the body of the robot as being constructed of a soft material. "Softness" is most often correlated with a mechanical property known as Young's modulus, defined as the relation between stress and strain for a linear elastic material. Soft roboticists Daniela Rus and Michael Tolley thus define soft robots as "systems that are capable of autonomous behaviour, and that are primarily composed of materials with [Young] moduli in the range of that of soft biological materials" (Rus & Tolley, 2015: 467).

In relation to robotics research in general, the field of soft robotics distinguishes itself by utilizing bio-inspired design strategies (often coupled within an interest in *morphological computation*) as well as an interdisciplinary outlook that seeks to combine research from engineering, computer science, biology and material science (Trimmer et al, 2015). Within soft robotics bio-inspiration has mainly come from soft bodied animals or parts of animals that are soft, e.g. larvae, cephalopods and the elephant's trunk.

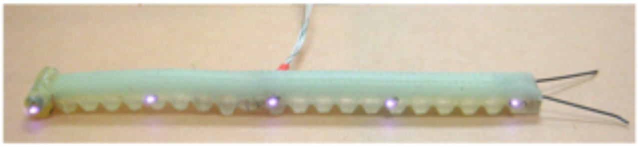

Figure 1. Caterpillar-inspired soft robot by Huai-Ti Lin, Gary G. Leisk and Barry Trimmer. © Huai-Ti Lin, Gary G. Leisk and Barry Trimmer.

Soft robots offer different conditions of possibility for interactions with humans than their more common rigid counterparts. From a naïve realist point of view it seems intuitively clear that this fact hinges upon inherent qualities of the materials from which they are constructed. Within technical and natural sciences research, these can easily be described with reference to the physical properties of e.g. silicone rubbers, which can be reproducibly measured and calculated. Physical descriptions, however, obviously miss the potential of soft robotics as an aesthetic, cultural and ecological phenomenon and elides the sensuous knowledge, cultural imaginaries and fascination the technology is able to conjure up. Approaching soft robots from the point of view of materiality, a first question thus becomes how to think in a way that allows one to escape the trap of a purely physicalist conception of matter (see Stoljar, 2016). And how one avoids its reductionism and violence towards knowledge, percepts and affects hailing from sensory perception or thinking constituted in practices and relations that lie beyond the grasp of positivist science.

Materiality

Within the social sciences and humanities a shift of interest towards materiality and matter has been evident for some time now. It is often described as a swing back from or reaction against the linguistic turn and its emphasis on semiotics and signification. Some of its most obvious manifestations are taken to be the emergence of *object-oriented ontology*, *speculative realism* and a number of so-called *new materialisms* (Atkins, 2016). The term "materiality" is, however, used in very divergent ways in the various contexts, fields and sub disciplines where it has made its presence felt. The theoretical movements just mentioned, for instance, are mainly interested in materiality from ontological and metaphysical perspectives. N. Katherine Hayles has written extensively about matter and materiality and distinguishes between *physicality* and *materiality*. Physicality, according to Hayles, is "similar to an object's essence; potentially infinite" and "unknowable in its totality" (Hayles, 2014: 172). Materiality on the other hand, is what we can know – "the physical qualities that present themselves to us" (ibid.). As Hayles notes, what qualities that "present themselves" obviously depends on how we attend to the object or material in question (ibid.) i.e. our choice of epistemology.

Drawing on this minimal definition of materiality, I will in the following two sections explore how the materiality of soft robots is constituted within two different contexts: the reception situation of contemporary media art and the fabrication and design processes within technical research practices. I review *how conditions are set up that enables the physical qualities of soft robots to be actualized* (i.e. to manifest themselves and be recognized). I also consider *the processes through which this occurs* and *what material characteristics that emerge from them*.

Soft Robots in Contemporary Media Art

A small number of artworks currently exist that make use of technological means that can be considered variations of soft robotic technology.[1] Jonathan Pêpe's installation *Exo-biote* (2015) is a notable example. It was produced in collaboration with soft robotics researchers at Université de Lille. The work consists of a transparent display case that contains several small white rubber parts in geometric and organic shapes, all kept in a very clean and designed commodity aesthetic.

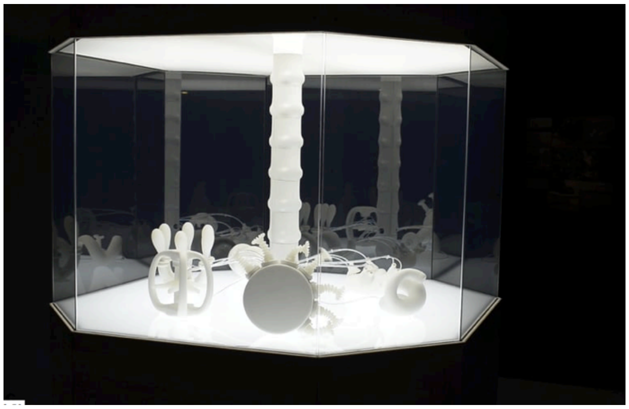

Figure 2. Jonathan Pêpe, *Exo-biote* (2015), Le Fresnoy, National Studio of Contemporary Arts; Neuflize OBC; INRIA, the DEFROST team. © Jonathan Pêpe

Some of the parts are able to pop up and whirl around or expand to provide movement. The piece has been described by the artist as a scenario that presents the viewer with a kind of artificial externalized prosthetic organs that come together as a pneumatic organism. In his view, it suggests a possibility for transhuman enhancement as a new mode of capitalist consumption (Pêpe, 2015).

Another example that is also the result of interdisciplinary collaboration between soft roboticists and an artist is *THE BREATHING WALL (BRALL)* (2015).

Figure 3. Ece Polen Budak and Ozge Akbulut, *BRALL* (2015) (detail), silicone on polycarbonate panel, 145 × 145cm. © Ece Polen Budak and Ozge Akbulut

This installation by Ece Polen Budak and Ozge Akbulut, was constructed in collaboration with Onur Zirhli and soft roboticist Adam A. Stokes from the University of Edinburgh. In the work panels of a silicone foam wall structure

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[1] I only review projects here that were produced explicitly in an art or artistic research context. Moreover, I only include work that makes use of microcontrollers or other means of computational technology in combination with a pliable or deformable soft morphology. There is currently also a burgeoning interest within architecture in utilizing soft robotic technologies. Michael Wihart's *Pneumorphs*, Bijing Zhang and Francois Mangion's *Furl* (2014), the *Sarotis Project* (2016) and Dino Rossi's work are examples of this. Many artworks of course also exists with more traditional uses of pneumatics – spanning the period from ancient China and Greek antiquity until today. Within contemporary art and media art pressurized air has also frequently been used to power piston actuators or McKibben artificial muscles or together with inflatables made of thin plastic. Soft robotic artworks also bear formal similarities to the tradition of *soft sculpture*, from the 1960s where a number of artists started using materials such as synthetic foams, rubber, soft plastic, paper, fabric and different kinds of fibres in their work.

perform a kind of breathing swelling motion. This movement is further augmented with audio recordings of human breathing sounds played through a set of loudspeakers. The audience can physically touch the structure and interact with the system as the large air pockets are inflated in accordance with input from capacitive sensing conductive plates installed behind the panels (Budak et al, 2016).

Paula Gaetano Adi's biomorphic half-spherical autonomous robotic agent *Alexitimia* (2006-2007) is another early example of a soft robotic artwork. Interestingly it was produced before soft robotics had become a prolific research field and it was designed and constructed by the artist herself. Like *BRALL* it interacts with audience members through touch. Here, however, yet another sensorial register is added: The tactile experience of soft latex rubber bending upon impact is accompanied by sensations of wetness as the sculpture responds to haptic stimulation with the secretion of a sweat-like fluid. Gaetana Adi posits the work as an exploration of "artificial corporeality" (as a supplement or alternative to artificial intelligence) and robotic body language (Gaetano Adi, 2007)

Figure 4. Paula Gaetano Adi, *Alexitima* (2006/2007), Autonomous Robotic Agent. © Paula Gaetano Adi

Looking at the artworks I have cursorily presented in this section, it is possible to discern some central aesthetic interests and tropes that seem to cling to soft robotics when constituted as an artistic medium. For one, in the reception situation of soft robotic art we are primarily dealing with a materiality that is accessible through bodily and corporeal engagement. In Budak and Akbulat's work as well as in Gaetana Adi's the viewer is physically implicated with the robotic system via a haptic aesthetics – in order to experience the work we must touch it. Pêpe's installation similarly alludes to touching but via negativa – the pristine white soft rubber parts are warded off from the viewer by transparent glass plates and thus a gratification of the desire to touch it is withheld. The act of touching a soft robot is, arguably, an experience that carries with it, if not uncanniness, then at least an amount of cognitive dissonance: We are all familiar with pliable soft surfaces that respond to our touch, but from living bodies not artificial entities. In this sense, there exists a cognitive contiguity between soft materiality and animatedness. This contiguity is also evoked in the breathing expansion motion that is used in *BRALL* but also in a number of other soft robotic artworks including Paula Gaetano Adi's *Anima* (2009) and Ingrid Bachmann's series *Pelt (Bestiary)* (2012). The swelling motion of a soft structure here serves as not just a signifier of liveness, but a simulation of its basic unit – the breath, in what amounts to a kind of primordial production of presence.

Through their use of touch and/or rhythmic expansive movement the reviewed works manage to stage and present select physical qualities of soft matter in expressive ways that conjure up their centrality in organic life processes in general. This is done through modes of presentation that rely on a direct interlinking with the human sensorium. Being that this occurs in the institutionalized art space the soft materiality of the works also inevitably expands to encompass cultural connotations of softness: Vulnerability (a quality also explicitly mentioned by Gaetano Adi when speaking of her work), weakness, the feminine (cf. the likeness between Gaetano Adi's robotic agent and a pregnant belly).

In the following section I will look at how the materiality of soft robots is constituted within technical research practices and discourses. As will become clear, technical soft robotics research brings questions of material transformation to the fore as both a resource and a matter of concern for robotics research.

Technical Soft Robotics Research

In technical research on soft robots the issue of materiality figures prominently as a key question has been which materials to use and how to most efficiently design and construct soft morphologies (Marchese et al, 2015; Rus & Tolley, 2015). The aim of developing new materials and reliable fabrication procedures has in fact served as a crux for an import of knowledge to the field from material science and also for its further development of existing rapid prototyping technologies.

Unlike traditional robots, soft robots are generally fabricated as continuous morphologies, rather than as assemblages of discrete components. This opens up the possibility for a different design and fabrication approach than when confined to assembling rigid mechanical parts as is usually the case for roboticists. A soft morphology is most often cast in a mold from a soft material such as silicone rubber. It might be tempting to see this procedure as being a version of the *hylomorphic scheme* as described by Gilbert Simondon. That is: as a fabrication procedure that is conceived as mind actively imposing a form on a "raw" matter that is inert and passive (Simondon, 2005). This is, however, misleading, I posit, as the two central points of Simondon's critique of hylomorphism are actually inherent to current soft robotic design and fabrication practices, namely that: 1. matter is not passive (but rather capable of contributing to the generation of its own form), 2. matter (in fabrication) is not raw but always prepared and produced.

Process and Material Transformation as a Part of the Fabrication and Functionality of Soft Robots

Some of the early pioneering soft robotics research came out of chemistry research in microfluidics, most prominently from the Whitesides Research Group at Harvard. In a number of soft robotics projects the capacity of matter to react with other kinds of matter and to transform given the right conditions is therefore an essential aspect. This is the case for what was promoted as the first fully autonomous soft robot and published in the prestigious *Nature* journal in 2016. It was fabricated by depositing various materials using a modified 3D printing platform equipped with syringes. Some of these materials would gradually evaporate to yield microfluidic air channels used for pneumatic actuation of the finalized morphology (Wehner et al, 2016). The design and fabrication scheme thus relied on transformational properties of matter, e.g. the capacity of fugitive inks to auto-evacuate. But what is more, the cyclical movement pattern enacted in the finalized robot was also accomplished by a pneumatic logic circuit driven solely by chemical reactions and no electronics. The robot's operation was rooted in making two fluids react to create a gas and a resulting pressure differential between the inside and the outside of the morphology's surface.

The research that is being done by the Soft Robotics Group at the Bristol Robotics Laboratory is another example of how the transformational properties of matter are being leveraged as not just a part of the fabrication process but for the actual functioning of soft robots. Here experiments are being conducted with biological means of generating electricity to drive soft robots by relying on microbial fuel cells and organic matter that is abundant in local ecologies. Moreover, rather than using silicone, which is manufactured though an energy demanding and elaborate process from sand and hydrocarbons and is very durable, the researchers are experimenting with using biodegradable materials such as latex rubber and gelatine. This is done to yield autonomous soft robots that may assimilate to and eventually perish in natural environments without causing damage to them. This visionary approach to soft robots highlights the fact that actual robots do not exist in an ahistorical vacuum of time, but have a life span and an entwinement with larger flows of matter that needs considering.

The Mangle of Practice

From the examples of technical soft robotics research I have surveyed in the previous paragraph it becomes clear that the enactment of a processual and dynamic chemico-biological materiality is central to the fabrication and functioning of certain state-of-the-art soft robots. If we look at descriptions of the creative process of designing soft robots, materiality also plays a vital and dynamic role here.

In a seminal article on soft robots from 2011 that introduced the *PneuNets* (*Pneumatic Networks*) actuation technology, which has since been widely used in soft robotics (and patented by the authors to be commercially exploited by their company), for instance, the authors write:

> "We used a series of parallel [air] chambers embedded in elastomers as repeating components. Using intuition and empirical experimentation, we stacked[31] or connected these repetitive components to design and test prototypical structures that provide complex motion." (Ilievski, 2011: 1891)

For the authors, who were all working in the Whitesides chemistry research lab, an embodied and situated knowledge combined with active material experimentation formed the substrate from which their invention sprung. The final design of the robot, it seems, was negotiated between human and non-human material agencies – both natural and historically contingent ones.

In a similar manner, a lot of soft roboticists look to nature as a source of inspiration. But soft robots are more often bio-inspired than biomimetic. That is, rather than being copies or technical remediations of biological mechanisms aimed at exact replication they extrapolate these, following their virtual lines of flight. The bio-inspired mechanics are then iteratively prototyped, using rapid prototyping tools, to arrive at a desired level of functionality in the final design (see e.g. Kovač, 2013). The translation of a mechanical principle observed in nature into technology is thus evidently negotiated through a series of entwinements between contemporary social needs and desires, technology and matter. This dialectic between *resistance* (obstacles on the path to a goal) and *accommodation* (the revision of conceptual models) is what Andrew Pickering has described as *the mangle of practice*. According to Pickering, it is the emergent process that gives structure to scientific research through an interplay of material, conceptual and social practices (Pickering, 1994: 262-3.

Experiments Toward Soft Robotic Ecologies

My own approach to soft robotics is characterized by an interest in the aesthetics of interaction between soft robots and humans also characteristic of the soft robotic artworks I have reviewed in this paper. This includes how softness affords a specific expressivity, how soft robots are perceived differently than rigid ones and how the cultural, symbolic and meaning making potentials of soft materials play into this. My focus is, however, not solely on human-robot interaction or the structure of the experiences it may give rise to. Soft robots are part of and shaped by a multiscalar material ecology that is physical as well as social and cultural. I aim to explore how acknowledging this fact may contribute to envisioning robots anew. Adopting an ecological framework, the task becomes to determine what the wider assemblages are that soft robotics couple with or make possible and how their materiality conditions or gains traction on experience, social forms, knowledge and politics and rearticulates them at different scales. I have been exploring this in a number of prototypes, some of which I will briefly present.

Entropy

Entropy is an early prototype constructed from silicone, silicone glue, wax and various found waste materials. It was constructed in a mold made of soil as a counteroffer to the sleek mass-produced commodity aesthetics characteristic of technical soft robots and as an insistence on a grounded non-idealizing aesthetic. The morphology performs a breathing motion at irregular intervals.

Figure 5. *Entropy* (2016).
Video: https://www.youtube.com/watch?v=y3MTcC0x5-g.
© Jonas Jørgensen

The prototype was one in a series of material experiments in combining highly elastic silicone with other materials.

Figure 6. Examples of material experiments. Left: Coloured EcoFlex silicone and beads of hydrogel were submerged in water. The beads become transparent, swell and expand the silicone. Middle: Silicone embedded with kitchen salt then cured in an oven and placed in water overnight to dissolve the salt. The resulting structures were easily compressible and sponge-like with perforated holes all the way through which allows air to pass from one side to the other. Right: Cured sheets of silicone doped with carbon black to yield electrical conductivity (the attempt was unsuccessful). © Jonas Jørgensen

The Fluid Medium

A number of more recent prototypes have been relocated from atmospheric air to an aquatic milieu – a future other organisms might face as the planet deteriorates further. These prototypes carry a technical interest in *morphological computation* (how soft materials can obviate the need for extensive computation in the control loop of a robot) over into aesthetic concerns: viscosity is explored as an *affordance* (Gibson, 1986) for silicone that enables biomorphic life-like movement. They also speculate on how a productive interplay between a specific milieu and a soft body can occur and how softness exists as an intermediate state between liquid and solid.

Figure 7. Physical coupling between a silicone appendix (cast onto a servo motor) and its containing medium (water). The arm produces fluid motion with gradual biomorphic bending when submerged in water but flaps clumsily around when in the air. Video: https://youtu.be/ifLChDLxdjE. © Jonas Jørgensen

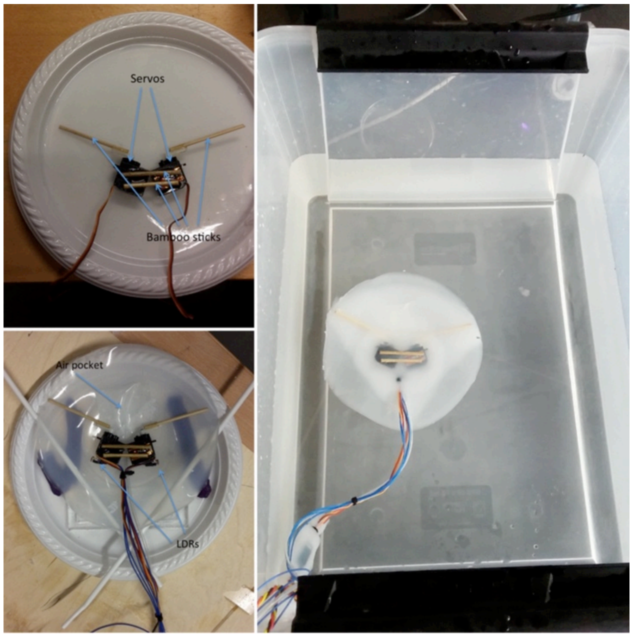

Figure 8. An improvised fishlike soft prototype was fabricated from silicone, bamboo sticks, epoxy, two servo motors and two light-dependent resistors. I plan to experiment with using evolutionary algorithms to evolve its swimming behavior. Video: https://www.youtube.com/watch?v=U7c0oTtsseU. © Jonas Jørgensen

Soft Robot-Plant Ecologies and Biohybrids

Phytomatonic is a series of prototypes that explore how soft silicone might afford an artificial agent other relations with biotic elements in an environment than rigid materials. The series also relates to questions on how we can speak and think about biological organisms and robots coming together in ways that go beyond instrumentality and anthropocentrism.

Figure 9. Soft robot-plant interaction. Video of the robot: https://www.youtube.com/watch?v=BO9zXX_XHr4
© Jonas Jørgensen

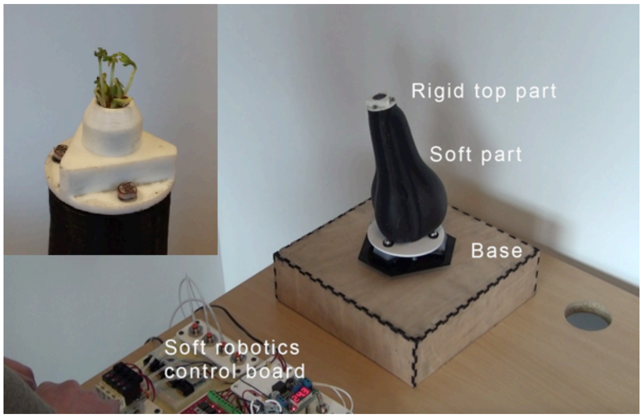

Figure 10. *Phytomatonic 01* (2016).The robotic part of the system and the rigid tip of the robot with the three LDRs and cress plants. © Jonas Jørgensen

The central element in the prototype *Phytomatonic 01* is a black soft robotic tentacle. This soft body is equipped with three light-dependent resistors (LDRs) at its tip that allow the robot to detect incoming light. Directly below each LDR are three separate air chambers that can be inflated with an electrical pump to actuate the robot and make it move. At the tip of the robot, ordinary cress plants are placed. The robotic part of *Phytomatonic 01* replicates characteristic aspects of a growing plant by means of soft robotics technology. More specifically: 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 plants 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. The technological part of the system succeeds in replicating a biological mechanism through the use of soft robotics technology but for a goal that from a practical viewpoint may seem entirely redundant: The robot is programmed to position the plants in the direction of the incoming light – something that the plants are perfectly able to accomplish on their own.

Figure 11. An overview of the prototype *Phytomatonic 01*. Video: https://www.youtube.com/watch?v=-awxAXI035E
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Conclusion

The embrace of soft materials by roboticists has the potential to radically change not only the appearance of their creations but also how they are able to relate to and interlink with their environments and other agents. This will obviously have consequences when the robots are brought out of research labs into "the wild". How will cultural narratives and imaginaries of softness, robots and artificial life conjoin in the encounter with a pliable robot? What meanings and modes of relating will emerge from soft materiality combined with artificial intelligence? Through the line of arguing and the examples presented in this paper, I hope it has become clear, that both artistic practices and technical research are important vehicles to address questions like these.

References

Atkins, P. (2016) *Liquid Materialities: A History of Milk, Science and the Law*. London: Routledge.

Budak, E. P. et al (2016). "The Breathing Wall (BRALL)—Triggering Life (In)animate Surfaces." *Leonardo* 49, no. 2, 162–63.

Gaetano Adi, P. Video: http://paulagaetanoadi.com/works/alexitimia/ (accessed March 20, 2017)

Gibson, J. J. (1986). *The Ecological Approach To Visual Perception* (1 edition). Boston: Psychology Press.

Hayles, N. K. (2014). "Speculative Aesthetics and Object-Oriented Inquiry (OOI)." *Speculations: A Journal of Speculative Realism* V (2014), 158-179

Ilievski, F. et al (2011). "Soft Robotics for Chemists." *Angewandte Chemie International Edition* 50, no. 8, 1890–95.

Kovač, Mirko (2013). "The Bioinspiration Design Paradigm: A Perspective for Soft Robotics." *Soft Robotics* 1, no. 1, 28–37.

Marchese, A. D. et al (2015) "A Recipe for Soft Fluidic Elastomer Robots." *Soft Robotics 2*, no. 1, 7–25.

Pêpe, J. (2015) "Exo-biote. Installation". Retrieved Nov. 12 2016 from Panorama 17 website, http://www.lefresnoy.net/panorama17/artwork/573/exo-biote/jonathan-pepe#artwork

Pickering, A. (1994) "The Mangle of Practice" in: R. C. Scharff and V. Dusek (eds.) *Philosophy of Technology: The Technological Condition: An Anthology* (2014), 2nd ed. West Sussex: John Wiley & Sons.

Rus, D. & Tolley, M. T. (2015) "Design, Fabrication and Control of Soft Robots." *Nature* 521, no. 7553: 467-475.

Simondon, G. (2005) *L'Individuation a` la Lumie`re des Notions de Forme et d'Information*. Grenoble: Ed. Je´roˆme Millon.

Stoljar, Daniel, "Physicalism", *The Stanford Encyclopedia of Philosophy* (Spring 2016 Edition), Edward N. Zalta (ed.). Retrieved from http://plato.stanford.edu/archives/spr2016/entries/physicalism/.

Trimmer, B. et al (2015) "ROUNDTABLE DISCUSSION Soft Robotics as an Emerging Academic Field," *Soft Robotics*, vol. 2, no 4.

Wehner, M. et al (2016). "An Integrated Design and Fabrication Strategy for Entirely Soft, Autonomous Robots." *Nature* 536, no. 7617, 451–55.

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