# The Rise of Organic Soft Robotics : Strategies for Fabrication

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Soft Robotics rapidly emerged as an area of interest in Human-Computer Interaction (HCI). Simple DIY fabrication processes and platforms were re-adapted from traditional digital fabrication tools, resulting in making soft materials-based prototyping accessible to the design and maker community. There is a growing interest in the use of bio-based and bio-degradable materials in design and prototyping, creating discussions around sustainable design practices as new motor of interdisciplinary exchange. These materials are abundant in Nature, have properties extensively explored in bio-engineering, and are potent in driving sustainability. However, soft robotics and shape-changing interfaces are not yet developed using these new materials alternatives. In this context, we highlight potential materials and advocate for their democratized use in soft robotics and HCI. More precisely, we propose an empiric overview of the main challenges in prototyping with bio-based and/or bio-degradable materials, pointing therefore how fabrication processes and tools need to be adjusted once again.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**.

Additional Key Words and Phrases: Soft Robotics, Bio Materials, Human Computer Interaction

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## 1 INTRODUCTION

As a constantly evolving and interdisciplinary field, HCI creates technological novelties and accessibility by binding and constantly transferring knowledge between various research communities. Inspired by natural soft structures such as skin and cartilages [22], and taking advantage of the advancements in material science [25], robotic engineers incorporated soft structures into their designs. These structures present user-safe and shape adaptable or retaining properties [1]. Therefore Soft Robotics, alongside soft actuators and interfaces rapidly emerged as areas of interest for both HCI and Human-Robot Interaction (HRI) communities [5]. By combining relative simplicity of manipulation and unique mechanical properties, silicone elastomers made their way as one of the main materials used in the design of soft structures [12, 33].

Willing to go beyond the bio-inspiration, the design and materials science communities studied functional bio-polymers[1] for different applications. While the design community is mainly driven by societal and sustainability concerns

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[1] bio-based and bio-degradable polymers with basic processing of the raw material

and seeks aesthetics and awareness, the material science community is driven by functionality and bio-compatibility[2] for bio-engineering applications.

Organic and bio-based materials are abundant in nature, and few works exists to demonstrate the potential for soft robotic applications [15, 16, 32, 35]. Bridging the gap between Design, Robotics and Material Science is a new challenge, that should consider material knowledge and process and tools.

Regarding *Material Knowledge*, the Design community developed multiple **bio-material banks** [10, 11, 27] gathering DIY synthesis processes and properties visual and tactile evaluation. However in the case of HCI and Soft robotics this is not sufficient. Understanding the properties, synthesizing and making functional materials from those bio-polymers often requires extensive chemistry knowledge and highly parametric environments. The *processes and tools* used in HCI community promote and embody technological and frugal accessibility, which is not the case in Material Science. Due to the inherent specificities of these materials (important retraction, warping during drying, shearing and tearing fragility, moisture absorbtion), the fabrication processes used in silicone actuators fabrication (molding/casting, 3D printing, heat sealing) need to be adapted or completely rethinked. There is at the moment a lack of data on these alternatives regarding the fabrication processes, the function they can achieve and their limits.

In this position paper, we identify the main challenges of working with bio-polymers in HCI and Soft Robotics and proposes recommendations and areas that need to be explored in order to make these materials accessible for prototyping based on our empirical experience. To built on this work, we present the fabrication inflatable actuators with conventional materials trough the most common processes used in Soft Robotics (molding, heat sealing, manual heat sealing and 3D printing/self healing) and then tried to reproduce them with bio-polymers. This work is a first step towards bio-based shape-changing interfaces.

## 2 BACKGROUND

### Traditional soft robotics fabrication processes and materials for Pneumatic Actuators

Fluidic soft robotic actuators fabrication is currently explored through various process. Pneumatic soft robotic fabrication is mainly based on silicone elastomeres, TPUs and other synthetic materials for the outer shell design and working with these materials can be achieved with different processes: Mold casting is the most common process and was extensively explored for the fabrication of soft actuators [41]. Molds are composed of one or multiple parts and can be cast using commercially available silicone elastomer [37]. However molding processes have showed limitations in the reproduction of complexes geometry or internal features and are labor intensive. To overcome the design freedom limit lost wax casting [23] was used to produce ephemeral core elements but at the depend of the cost and complexity of the method. Molds being reusable elements make this techniques relatively economic, but still time consuming. The progress in fused deposition modelling [3] (FDM), stereolithography (SLA) [38] and digital light processing (DLP) [13] made theses methods more commercially available and accessible in the designers, researchers and makers communities. Additive manufacturing offer the possibilities to design parts with geometries that wouldn't be otherwise possible, the ability to modulate the material stiffness and elasticity [2] and the opportunity to quickly iterates in the fabrication of soft actuators. The Heat sealing process is investigated for the manufacturing of planar soft actuators, offering a viable methods to form bending actuators out of planar shapes which deformation are controlled through bonding patterns[8, 30] and superposition of materials exhibiting different stiffness and elasticity.

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[2] property of a material being compatible with living tissue. Bio-compatible materials do not produce a toxic or immunological response when exposed to the body or bodily fluids.

Fabricating soft actuators and interfaces is itself a challenging task, often requiring engineering knowledge or the use of specialized equipment. To enhance their accessibility, new manufacturing methods [34] and multiple toolkits for soft interfaces [20, 29, 38] were created.

### Shape Changing Interface

Shape changing interface (SCI) is an emerging fields in HCI [7, 9, 26]. These non-rigid or kinetic interfaces can exhibit moving, elastics, flexible, bendable, stretchable, malleable, reconfigurable or even inflatable characteristics for interactive applications. These interfaces represents opportunities to re-define tangible interactions gesture [18, 33, 36] and to replace or augment their non-rigid counterparts. Certain SCI [21] share their properties with soft robotics actuators, particularly those using fabrics [14] or soft and malleable rubber-like materials with inflatable behaviours. Both being able to adapt themselves to several shapes, capable of sensing and of actuation.

### Organic soft materials

Other than creating technological novelty, reflecting on the moral values embedded in our designs is another important role of HCI community. Therefore, going beyond bio-inspiration, by designing with bio-polymers such as gelatin [2, 6] and actuators and sensors [19, 39] using living or organic materials have been investigated. However, their study for HCI or Soft robotics applications remains restrained compared to the extensive research done in material science [16, 35, 40] that show the elastic (& other) properties of those materials and the previsions made for Soft Robotics [4].

## 3 EMPIRIC OVERVIEW OF THE CHALLENGES

In this section, we propose through examples an empiric overview of the main challenges in prototyping with bio-based and/or bio-degradable materials. We highlight the relation between materiality and fabrication processes. To do so, four actuators were fabricated using conventional materials and processes - molding, manual heat sealing, digital heat sealing, and 3D printing / layering, and then replicated using biopolymer materials.

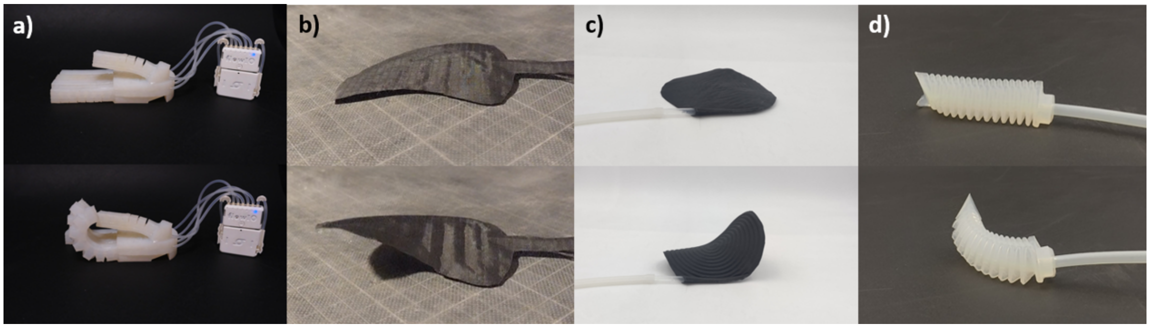

Fig. 1. Each actuator is shown in relaxed state in the top picture and actuated in the bottom picture (a) Molding: Pneu-Net grippers made of silicone, (b) Manual heat-sealing: fin-like actuator made in TPU-coated nylon fabric, (c) Digital heat sealing: Archimedean spiral actuator made in the same material, using a modified CNC Machine and a soldering iron [cite benoit ?] (d) 3D printing : silicone actuator printed in one step process

## Anorganic Soft Robotic

Pneu-Net soft actuators were molded using a resin 3D printed mold and Dragon Skin™ 10 FAST elastomer using the process described by Ilievski et al. [17] - the fabrication comprises 4 main steps: molding the creased upper part, molding the plane lower part, fusing them using the same elastomer and finally attaching the airtube. The prototype presented in Figure 1a combines 5 of these actuators as a pneumatic hand and was realized and made into action over a single day. Fin-like inflatable actuators were made by sealing at 230°C two TPU-coated nylon sheets of fabric following a predefined pattern manually using a soldering iron and a paper stencil with an arbitrary pattern (Fig.1b) and using an adapted CNC Machine by replacing the drill head by a soldering iron at the same temperature using the method and the patterns developped by Siefert et al. [30] (Fig. 1c). Lastly liquid 3D printing was used to make the last pneu-net actuator using a Lynxter S600D LIQ11 printer with shower sealant silicone cured for 12 hours.

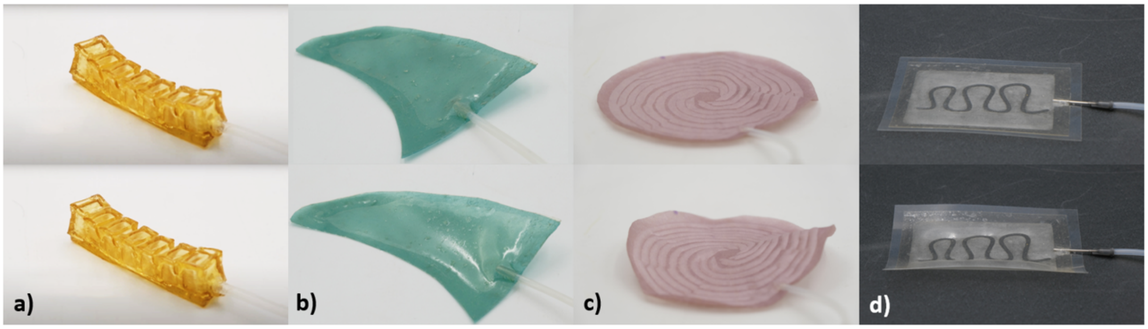

Fig. 2. Each actuator are shown in relaxed state in the top picture and actuated in the bottom picture (a) Molding: Pneu-Net grippers made of gelatin (b) Manual heat-sealing: fin-like actuator made in agar agar (c) Automatic heat sealing: spiral-like actuator made by pressing two agar agar sheet with a piece of baking paper conveniently shaped sandwiched in between using a pattern develloped by Siefert et al [31] (d) Self-Healing : alginate bioplastic sheets self-healed over baby powder stencil-painted pattern

## Organic Soft Robotic

Figure 2a presents the analog version of the pneu-net gripper made of a gelatin-based hydrogel using INKA Foods Bovin Halal Gelatin (250 bloom), replication of Shintake et al. work [28]. The other three actuators were made using alginate and agar-agar, two common biopolymers extracted from algae and used as additives in food industry. For the heat sealed actuators an agar-agar bioplastic sheet was used to replace nylon, first using a manunal soldering iron at 150°C 2b) and then using a hydraulic heat press at 150°C with a digital plotter cut baking sheet sandwiched in between the agar-agar layers. Lastly, we used alginate bioplastic sheets (Biozoon ALGIZOON) and their self-healing properties to create a planar deformable actuator by creating inversed patterns with acetate stencils and baby powder

## Challenges

*Material challenges.* The **quality** and **origin** of the materials used is crucial. Different types of gelatin with different blooming indexes will give completely different results [24]: using INKA Foods Bovin Halal Gelatin with 250 bloom index resulted in very stiff and tough samples compared to the ones obtained by Shintake et al. [28] using gelatin with a 100 bloom index. This is also the case for the alginate, more specifically, the species and origin of algae used and the glycemic index of glycerin that which are often not mentioned on the off-the-shelf products. Another important

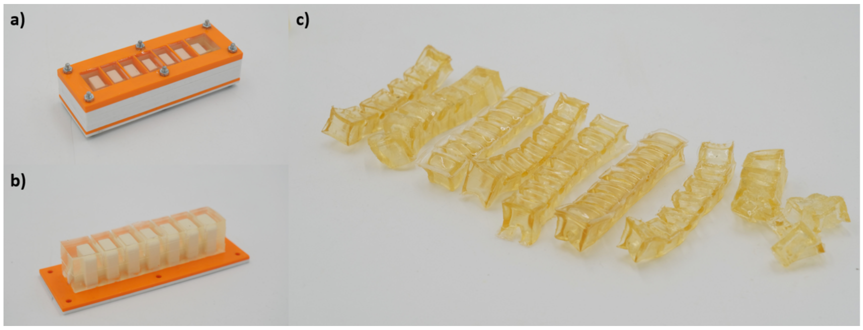

Fig. 3. Molding process for a gelatin pneu-net actuator (a) in the mold (b) opening the mold (c) trials and errors

aspect during the preparation of the heat synthetized hydrogel solutions is the **recipient**: using a recipient with a large diameter allows faster water evaporation and, therefore a lower water content in the molded hydrogel.

*Fabrication challenges.* **Water evaporation** was identified as an important factor during the fabrication of the actuator. While testing different variations of the ratios of gelatin:glycerin:water we experienced **shrinking** between 10 and 40% in all directions during the drying process of the gripper. This is also the case depending on the **drying conditions** : drying inside or outside the mold, airflow, temperature and humidity in the room, all have a direct impact on the structure and properties of the materials. The shrinking caused tearing of the material and 3D mechanical deformation for the samples with high water concentrations or low glycerin concentrations (Fig. 3c).

## 4 DISCUSSION AND CONCLUSION

Soft robotics and shape-changing interfaces prototyping and fabrication still rely on silicone, TPUs, nylon and other current mainstream materials. They present attractive properties because of the relative simplicity of manipulation, their availability. At the age of sustainability challenge for HCI prototyping, this position paper presents an initial exploration of bio-based and organic materials for soft-robotics and shape-changing interfaces. We use a series examples to reflect on the challenges of using bio materials. While the material properties are analog to traditional DIY materials, the fabrication process with the bio-based materials is more challenging. The effects of agar-agar, gelatin and alginate that are dependant of their source origin, the environmental conditions of their manufacturing and in their usage (such as their life cycle, important warping during drying and overall ambient moisture resistance). Some of these inherent properties can be used as part of the process in the case of self-healing, but remain limitations factors for their in-depth applications in scientific research .

They are also harder to interface with normalized equipment: planar hose connections of actuator with silicone tubes require many adjustment and differences in materials nature are creating constraints. There is a lack of connectors that should be further explorer in future work

However they represent a whole potential design space and need appropriation from researchers and designers. Some effort should be spent to accommodate existing methods for organic materials even if those are easily accessible. They represent opportunities in in-situ fabrication and low tech lab/communities notably for the right to failure inherent to the materials (being reusable and/or compostable).

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