

7. Soft living artefacts: design-driven exploration of engineered living materials

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ABSTRACT

In recent years, design scholars have introduced Living Artefacts as a novel class of objects that are alive, responsive, and relational. A promising yet underexplored area lies at the intersection of design, Human Computer Interaction and synthetic biology. In this context, Engineered Living Materials (ELMs), developed by bioengineers, show life-like traits such as self-regeneration, autonomy and environmental responsiveness. These materials could inspire the design of soft robots and artefacts that support well-being. This chapter presents findings from a Studio conducted at the TEI25 Conference in Bordeaux, where participants explored an ELM, an augmented silicone embedded with proteins, through hands-on, design-led experimentation. The session examined the potential of ELMs beyond bioengineering and prompted critical reflection on opportunities, challenges and ethical considerations at the convergence of bodies, design and living matter.

7.1 Introduction

Design research has increasingly explored the integration of living organisms such as algae, bacteria, fungi, and plants into the design process and design outcomes. This tendency translates into material choices aimed at reducing the environmental footprint of products while also expanding material expression. The use of bio-based materials, which are derived from living or once-living substances, shows important opportunities due to their biodegradability and for their sustainable life cycles. This shift in material innovation reflects a growing commitment in reducing environmental impact in interactive product design (Blevis, 2007), while also fostering new sensory experiences that engage users with physical matter in novel ways (Bell *et al.*, 2022; Lazaro Vasquez *et al.*, 2022).

Despite these advancements, many bio-based design outcomes merely mimic the aesthetics of living organisms rather than embodying true biological functions. In response, a new wave of Biodesign research is emerging to extend the concept of Livingness, shifting from objects that merely contain biological elements toward products that sense, grow, adapt, and eventually decay as part of their lifecycle (Karana *et al.*, 2020). This perspective challenges traditional ideas of material permanence, inviting designers to embrace temporality and transformation as inherent process of any designed artefact.

Parallel to these developments, the field of Human-Computer Interaction (HCI) has increasingly focused on materiality as a lens for design, investigating how materials shape and mediate interactions. Rasmussen *et al.* (2012) propose a framework for shape-changing interfaces, where shape change is increasingly used in physical user interfaces, both as input and output. Moreover, researchers have explored material programming as a way to develop novel interaction modalities, including temporality in interaction design (Vallgård *et al.*, 2013), somaesthetic explorations (Tsaknaki, 2021), and tension-and-release mechanics (Winters *et al.*, 2022). These approaches draw inspiration from biological and natural systems, mimicking their dynamic, responsive, and adaptive behaviors to create richer, more embodied interactions between humans and machines. Several researchers are experimenting with Interactive, Connected, and Smart

(ICS) materials, giving purpose and applications to advanced materials through a design-oriented approach (Parisi *et al.*, 2024).

Another promising direction focuses on soft systems – flexible, organic, and often biologically inspired materials that mediate human-technology interactions. For instance, Soma Design (Höök *et al.*, 2019) and Vibrant Wearables (Tsaknaki *et al.*, 2021) investigate how technology can be embedded into materials that not only conform to the body in an unintrusive way, but also respond to its movements, rhythms, and affective states. These explorations push beyond conventional rigid interfaces, suggesting a future in which interaction is fluid, organic, and intimately connected to the user's physical and emotional experiences.

7.2 Engineered living materials and soft robots

Advanced materials with life-like qualities, such as sensing and adaptability, are becoming key to designing next-generation interactive systems. Parallel to this, synthetic biology is opening new interdisciplinary opportunities, particularly with the development of Engineered Living Materials (ELMs) – materials designed by bioengineers to exhibit self-regeneration, environmental responsiveness, and adaptability. Nguyen *et al.* (2018) define ELMs as engineered materials composed of living cells that form or assemble the material itself, or modulate the functional performance of the material in some manner. These features surely hold exciting potential for interaction design where the interaction is deeply tied to materiality.

Within this context, soft robotics stands out as a particularly promising field. Soft robots, constructed from highly flexible materials that imitate living tissues, can perform tasks that rigid robots struggle with, such as delicate manipulations and organic, fluent movements. Despite their widespread use in biomedical applications, their role within HCI and interaction design remains underexplored. Yet, their ability to respond, adapt, and interact physically suggests new design possibilities, particularly in Tangible Interaction Design, where material and form influence user engagement.

Escaida *et al.* (2025) present an interactive art piece that combines soft robotics with tactile engagement, exploring the sensual and responsive potential of robotic systems. The installation features soft, flower-like robotic structures that respond to human touch, inviting participants to experience a unique form of human-robot interaction that emphasizes intimacy and sensory connection. A sustainable solution to soft robots is presented by Den Teuling *et al.* (2024) presenting chitosan, a widely available biodegradable actuator that absorbs moisture from air and undergoes shape changes in response to fluctuations in humidity (Figure 1). Besides the material, the researchers conducted generative sessions where participants interacted with the chitosan films, giving suggestions to the user interaction and experience of such material.



Figure 1.
Chitosan sustainable actuator (Den Teuling *et al.*, 2024). Photo Credits from the authors of the projects.

Grasping the user interaction with this new class of material is deeply relevant. On this regard Brocker *et al.* (2023) provide a comprehensive map of soft robotics shapes investigating how such shapes influence user perceptions and associations. The study provides insights for developing soft robotic devices that align with user expectations and enhance overall experience. Ultimately, as advancements in ELMs and soft robots continue to unfold, new opportunities emerge for interaction design that moves beyond rigid, static interfaces toward more fluid, adaptive, and sensory-rich experiences.

7.3 Studio's overview and structure

To delve deeper into these possibilities, the author (together with Professor Venere Ferraro, Professor Neel S. Joshi, and Valeria Regis) conducted a design Studio at TEI 25 (Tangible, Embedded and Embodied Interaction) conference in Bordeaux, France.

The Studio explored three artefacts designed for sensory and intimate interaction with the body: a menstrual cup, a breast pump, and a sex toy. These products come into direct contact with the body—around it and, in some cases, even within it. Particularly the sex toy chosen was dual-use toy, versatile sex toy working for both grinding (external stimulation) and stroking (penetrative or stroking motion).

Currently, all three artefacts present several user experience and usability challenges that could potentially be improved through the enhanced properties of the augmented silicone. These challenges range from design and material choices to interaction, adaptability, and accessibility for diverse user groups. The Studio had three goals:

1. exploring how ELMs could enhance traditional materials, giving them new functional properties;
2. examining how soft robots could improve user experience in the analyzed artefacts;
3. critically reflecting on interdisciplinary collaboration between design and biology in creating Living Artefacts.

Through iterative prototyping and discussions, participants explored how ELMs could transform the usability, comfort, and interaction of these artefacts while addressing the challenges and ethical considerations of integrating living materials into everyday products.

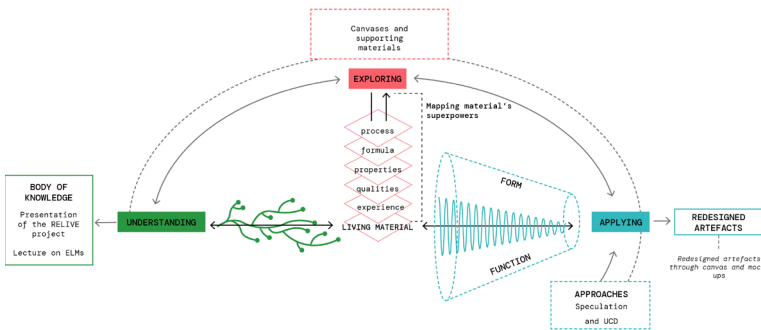
The Studio's structure followed an adapted framework (Figure 2) developed during the former Erasmus+ project DATEMATS (Ferraro V. 2021).

- *Understanding*: this phase concerns getting the fundamental body of knowledge as first step of the process. In the Studio this phase were two presentations, one about the project and another one about the augmented silicone held by Professor Joshi. Participants were introduced to ELMs learning what they are, how they are programmed, and explore their *augmented* life-like abilities.

- *Exploring*: the emphasis on the designer getting knowledge on the materials and processes by documenting and evaluating. Participants divided into three groups began by mapping both the areas of improvement of one of the chosen artefacts, in terms of user experience, and the *superpowers* of the silicone (for instance, a programmed material behavior in response to an input).
- *Applying*: From an ideation phase supported by canvases provided by the organizers, participants drafted scenarios, thinking about specific user and context of use. The challenge was to understand how a specific behaviour (programmed within the material) could improve usability of the artefacts. From this process, participants developed their idea, further representing their scenarios of interaction visually and through physical mock-ups.

The Studio was an immersive, full-day experience, culminating in a closing roundtable where participants shared their outcomes and reflected on the process they followed. A key highlight was the diverse disciplinary backgrounds of the participants – some adopting a material-driven design approach, while others focused on a human-centered perspective. This diversity in approaches to livingness fostered dynamic discussions, demonstrating that an interdisciplinary lens is valuable when designing living artefacts.

Figure 2.
The DATEMATS process adapted to the Studio.



7.4 Materials explored

The key focus was augmented silicone, a material developed by Professor Neel S. Joshi's research team at Northeastern University, which embeds proteins within silicone to enhance its electro-mechanical properties. Silicone is already used for soft electric actuators, but with embedded proteins, it could lead to lighter, more energy-efficient, and more responsive interactive materials. Examples of potential future applications include wearable actuators capable of augmenting and supporting human movement, such as an assistive sleeve for lifting heavy objects.

Figure 3.
The three artefacts.
Photo Credits from the authors of the projects.



We explored two kinds of materials. On the one hand we looked at three products carrying several issues related to user experience: menstrual cup, breast pump and sex toy (Figure 3). On the other hand, bioplastic films and augmented silicone with embedded proteins, programmed to carry out specific tasks. The silicone rubbers with embedded proteins can be compared to the same rubber composition without the embedded proteins to directly experience the difference in their *feel* (i.e., mechanical properties) in a tactile manner. For this reason, regular silicone was brought for building low fidelity prototypes, among other materials. Since the augmented silicone is still in a development phase, the outcomes of this Studio are speculative artefacts and scenarios.

To guide the ideation process, the organizers provided participants with a structured canvas and a set of supporting cards (Figure 4). The canvas was carefully designed to align with the three phases of the DATEMATS process (Understanding, Exploring, and Applying) to systematically lead participants from the identification of

user experience issues, to the ideation of potential solutions. In the Understanding section, participants were encouraged to analyze the current user experience of specific artefacts, focusing on identifying pain points, limitations, and challenges that regular users encounter. This step ensured that ideas for improvement were grounded in real user experiences. In the Exploring section, participants picked one of the *superpowers* associated with the augmented silicone. These *superpowers* represented unique properties or functionalities that could potentially enhance user experience and usability. Participants were guided to explore and experiment with these superpowers, matching them to the challenges they had previously identified. Finally, in the Applying phase, participants selected and integrated the most promising superpower (s) into their design concepts, envisioning how these material properties could lead to tangible improvements.

To further support participants, especially those who had not personally used the artefacts under discussion, the organizers also provided a set of hint cards. These cards included pre-identified pain points related to different artefacts, offering concrete examples to spark discussion and ideation. For instance, in the case of menstrual cups, the cards listed common challenges such as:

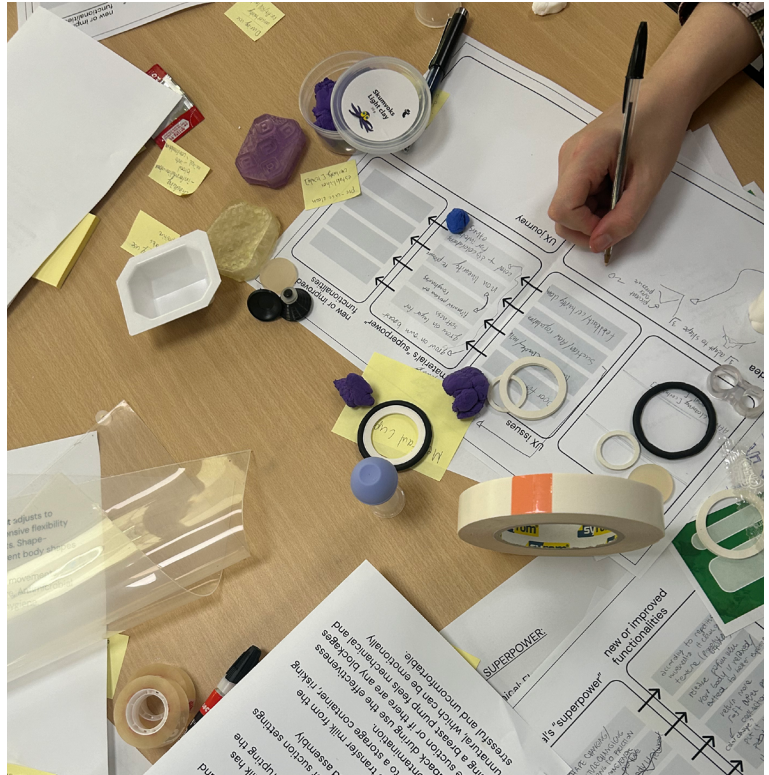
- difficulty in removing the cup without discomfort or pain;
- the cup not easily coming out, requiring effort or specific techniques;
- a sensation of the cup feeling like a foreign object inside the body;
- discomfort related to dealing with menstrual blood;
- hygiene challenges, especially in public restrooms without access to water or private spaces.

These hint cards served as a valuable tool, ensuring that all participants – regardless of prior experience using the artefacts – had a clear starting point for ideating potential solutions leveraging the life-like properties of the silicone.

7.5 Studio results

The results of the workshop reflected the diverse backgrounds and perspectives of the participants. Some approached the challenge with a more user-centered mindset, while others focused on the material itself. Despite these differences, all the resulting ideas leveraged the unique properties of augmented silicone to address issues in the user experience (Figure 4). Four ideas are presented here in detail, followed by final considerations in the concluding section.

Figure 4.
Filling the canvas while
developing mock-ups in
silicone.



7.5.1 Augmented sex toy

This idea began with the user journey of a sex toy, divided into three phases: pre-use, during use, and post-use. In the pre-use phase, there is high anticipation and excitement. During use, the experience is often characterized by frustration, with common thoughts including: «sticky», «cold», «too plastic», and «unsure if I'm using it correctly». The post-use phase is marked by disgust, with the primary

concern being, «how do I properly clean it?».

With new and improved functionalities, the user journey becomes an interactive experience, where the object adjusts to the body's responses, providing a more engaged and personalized encounter (Table 1).

UX issue	Material <i>superpower</i>	New or improved functionalities
Low stimulation	Shape-changing texture according to friction	According to repetitive movements it changes texture
Feels too <i>plasticky</i>	Contraction sensors	Returning softer when sensing contraction
Unsure about the correct usage	Hormone sensors	Releasing scent when the body is relaxed for a better experience

Table 1.
Augmented sex toy, summary table.

7.5.2 Personalized breast pump

This idea stemmed from the widely perceived discomfort of breast pumps, which are often seen as painful and not adaptable to different body shapes. The user journey describes an uncomfortable, impersonal interaction with the machine, leading to negative experiences for the user (Table 2).

UX issue	Material <i>superpower</i>	New or improved functionalities
Poor fit	Growing into a surface and taking the shape/texture	Growing a bacterial cellulose layer adapted to each one's nipple conformation
Suction and flow regulation	Contraction sensors	Getting firmer and returning softer according to the suction

Table 2.
Personalized breast pump, summary table.

The improved user journey with these new functionalities focuses on a more intimate, less painful, and personalized breastfeeding experience. This solution could offer a more inclusive and adaptive approach to accommodate various body shapes and comfort levels, eliminating the need for users to adapt to the machine.

7.5.3 Responsive menstrual cup

The menstrual cup was the chosen object for this idea. The user journey is divided into three phases: pre-use, during use, and post-use. In the pre-use phase, users feel a sense of pride for choosing a more sustainable option. However, during use, the main feelings shift to discomfort due to the challenges of insertion and hygiene, particu-

larly in public spaces. Users often experience uncertainty and fear of losing control, as it can be difficult to determine when the cup is full, especially with a heavy flow. Post-use frustration arises due to the difficulty in removing the cup and the messiness involved, especially because the cup can become very dirty from the blood.

With the new and improved functionalities, the user journey becomes more secure, helping in both inserting and removing the menstrual cup, while ensuring a cleaner and more controlled experience (Table 3).

Table 3.
Responsive menstrual
cup, summary table.

UX issue	Material <i>superpower</i>	New or improved functionalities
Missing information about blood level	Shape-changing texture	Changing texture in the stem to notify blood level
Difficult to fold to insert it	Mechanical properties (slowly returning to the original shape)	<i>Blocking</i> the cup for 20 seconds while inserting it then slowly releasing it
Difficult to remove it	Shape changing textures and mechanical properties (slowly returning to the original shape)	Clicking the stem and the cup <i>shrinks</i> , changing texture to facilitate removal

7.5.4 Final considerations

The three ideas presented are some of the ones developed during the Studio. They suggest the potential of Engineered Living Materials to support better user experiences. Each concept uses augmented silicone's unique properties – such as shape-changing textures, mechanical responsiveness, and sensor integration – to address common issues faced by users while approaching menstrual cups, sex toys, and breast pump. Whether it's improving comfort, personalization, or the overall user experience, these ideas while speculative suggest compelling possibilities for enhancing livingness within product and interaction design through material innovations.

At the end of the Studio, participants and organizers engaged in an open discussion to gather feedback on how the activities were conducted throughout the day, as well as on the tools introduced. The Understanding phase was considered well-integrated into the agenda and highly relevant to the design process. The Exploring phase was also deemed relevant, but participants noted that they could have benefited from more structured sub-tasks rather than the open-ended approach used in this case. The Applying phase was

found to be effectively embedded in the agenda and valuable to the design process.

All participants stated that the Studio provided them with a new perspective on living artefacts, introducing a method that could be integrated into their practice. However, they found the most engaging and motivating aspect to be the topic itself, so working with this type of artefact. This insight led organizers to reconsider whether the Understanding, Exploring, and Applying framework is fully suitable for a one-day workshop format.

7.6 Conclusion: shaping *soft* living artefacts

This chapter explored the emerging field of Engineered Living Materials (ELMs) and their potential to act as soft robots for designing in the context of intimate and bodily interaction. The Studio, conducted during the TEI 25 Conference, demonstrated the promise of *augmenting everyday* artefacts with living materials to improve their user experience, usability, and adaptability. By applying augmented silicone – a material with life-like qualities such as self-regeneration and environmental responsiveness – participants were able to reimagine the functionality and design of three artefacts: dual-use sex toy, menstrual cup, and breast pump. These artefacts pose user experience challenges, and they can benefit from the enhanced properties of ELMs, leading to more personalized, comfortable, and sustainable solutions.

The results of the Studio highlighted the interdisciplinary nature of such explorations, where design, synthetic biology, and HCI intersect to create novel and engaging user experiences. Despite the promising outcomes, the exploration of ELMs in design raises important ethical considerations, particularly regarding the integration of such living materials into everyday products. Issues the ethical implications of designing with living systems must be carefully addressed as this field continues to evolve.

As research continues to push the boundaries of materiality in design, the future holds compelling possibilities for more dynamic,

responsive, and *soft* living artefacts that not only serve functional purposes but also foster more intimate interactions between people and bodily products.

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