Tex(alive)

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TEX(alive): A TOOLKIT TO EXPLORE TEMPORAL EXPRESSIONS IN SHAPE-CHANGING TEXTILE INTERFACES

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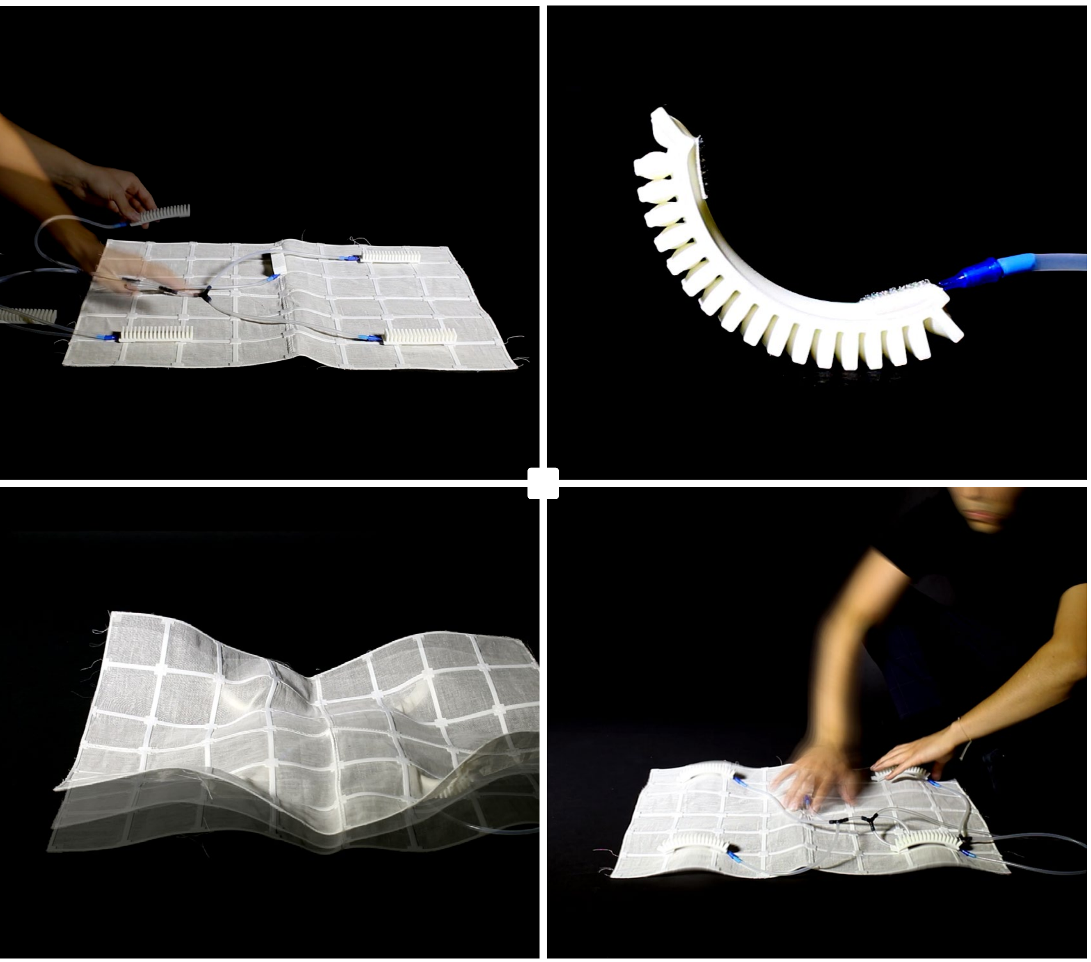

Abstract

Shape-changing textile interfaces have the potential to create unique functions, expressions, and interactions in everyday artifacts. However, the technical expertise required to fabricate and interact with these interfaces limits designers from rapidly iterating through diverse textile expressions. This pictorial presents TEX(alive), a low-cost and open-source physical-digital toolkit to facilitate the creation of temporal expressions in textile interfaces. TEX(alive) comprises pneumatic actuators that can be interactively configured across a 3d printed grid structure on the textile. Creative sessions with seven designers show that TEX(alive) supports the exploration of temporality in textile interfaces, opening up a design space for unforeseen future application scenarios and alive-like expressions in material-driven design. Finally, we suggest coupling TEX(alive) with a computational simulation tool to allow designers to predict spatial shape change when the textile interface increases in size or complexity.

Authors Keywords

shape-changing textile interfaces; pneumatics; temporality; design tools; material-driven design

CSS Concepts

Human-centered computing ~ Human computer interaction (HCI) ~ Interactive systems and tools ~ User interface toolkits

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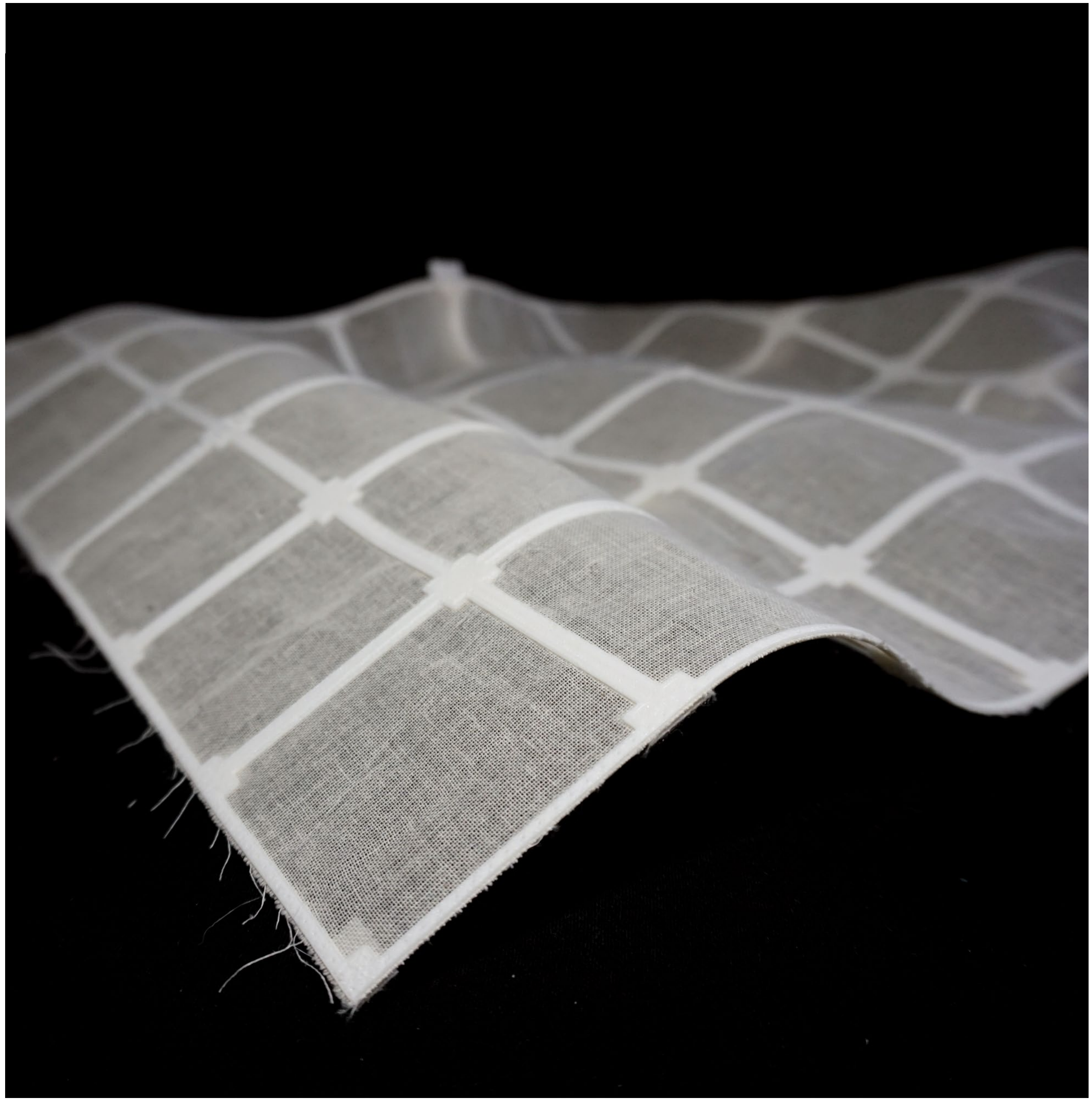
INTRODUCTION

Textiles are increasingly used in design and HCI as an active media to expand the possibilities introduced by ubiquitous and wearable computing [21,39] when combined with sensors and actuators [10,13,14,22] and smart materials [2,19,25]. For example, designers have augmented textiles with computation to serve as a support layer for graphical interactive elements on garments [16,24] or in home furniture [4]. Textiles have also been programmed as responsive materials capable of reacting, for example, to humidity [34] or heat [36].

More recently, HCI designers have developed novel techniques and vocabulary to explore the shape-changing possibilities offered by textile interfaces (see for example [12]). Shape-changing textile interfaces introduce a new design variable, i.e., temporality, in the creation of diverse form expressions. However, the technological complexity of shape-changing interfaces hinders the fine-tuning of their temporal qualities, limiting designers' creative contribution in discovering unique experiential potentials in material-driven design [18]. New tools are required for designing, prototyping and comparing diverse temporal forms [1].

To bridge this gap in designing shape-changing interfaces with textiles, this pictorial presents the low-cost and open-source TEX(alive) toolkit that helps designers explore temporal expressions with shape-changing textiles without prior technical experience, including its pneumatic control hardware and graphical user interface. We present how this tool is used by designers as a means to generate novel expressions and envisage future application scenarios. We further expand on the toolkit with a future concept of a computational tool to support the prediction of spatial shape change when the textile interface increases in size and complexity.



RELATED WORK

Temporality of Shape-Changing Interfaces in HCI

Traditional graphical user interfaces are programmed to respond as quickly and precisely as possible. However, shape-changing interfaces allow for new expressions as their form gradually evolves. Slowness, vagueness, and unpredictability in such interfaces [15] can lead to unique alive-like expressions [5] potentially eliciting a stronger response in interaction from users [38]. In textile interfaces, temporality has been explored as a means to elicit various emotional responses [9,3], to enhance social interaction [17,23], to explore the aesthetics and expressivity of computational technology [2,12,15,32], and more recently, to elicit unique actions from people [7]. As Vallgarda et al. [38] state, we must train designers in understanding the relationship between temporal and spatial form to move away from graphical interfaces and towards designing interactive environments. This mission is non-trivial as combining computation with textiles is a time consuming and complex process compared to producing traditional textiles. Efforts in engaging designers with lo-fi computation and textiles to reduce this barrier have already shown the promise of incorporating hands-on, experimental work to better understand the spatial-temporal relationship of these materials [21,28].

Shape-Changing Material Toolkits for HCI Designers

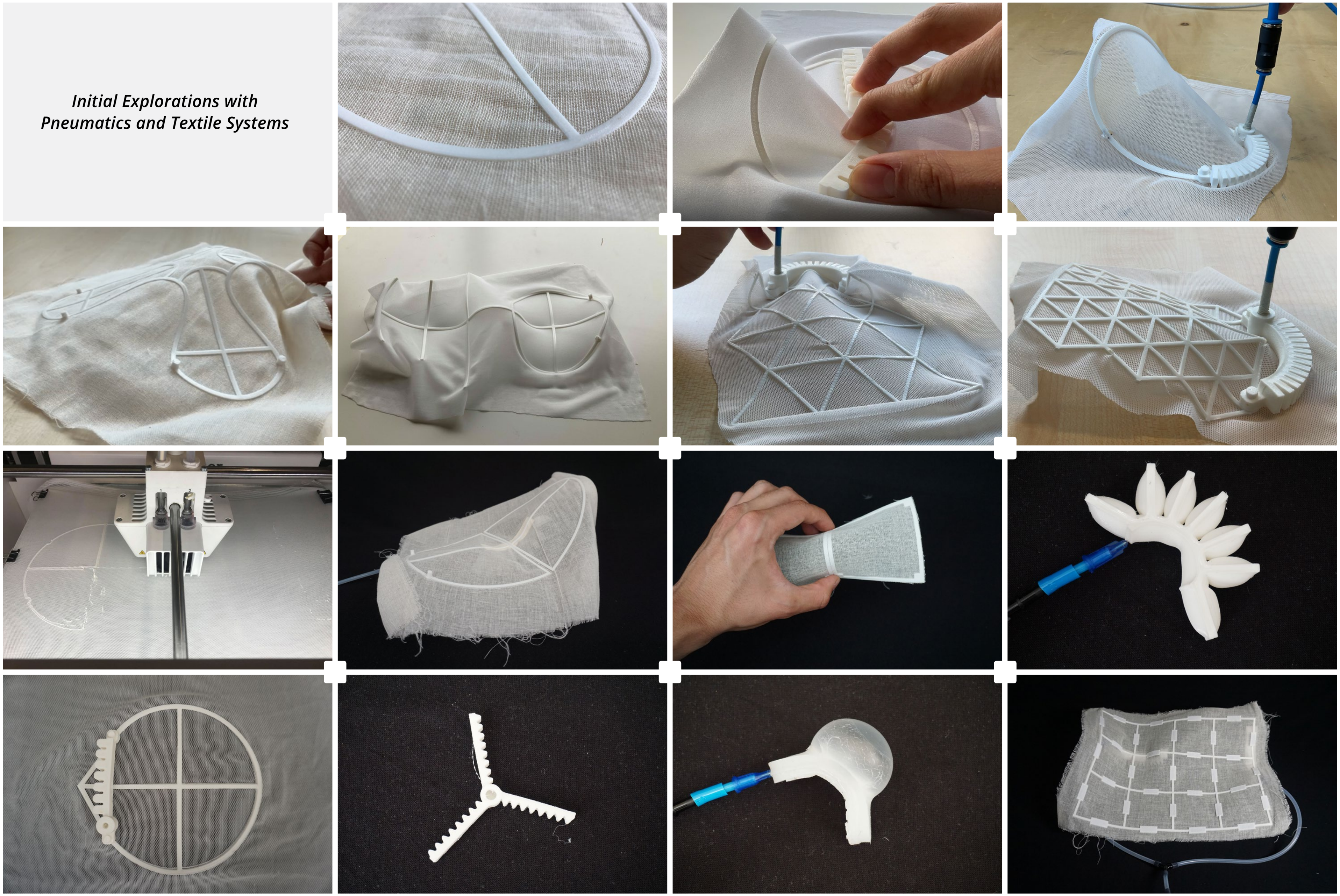
HCI researchers proposed diverse toolkits to support the design of shape-changing interfaces, for example, to simulate computer defined curved surfaces [35], animate static objects [26,27], digitally design different types of shape change [20], and ideate novel interfaces inspired by nature [31]. While these toolkits help introduce designers to the world of shape-changing materials, their main focus is on shape change as a static condition (changing from state A to state B) and lack focus on the temporality of the material. The transition of stages in shape-changing materials is more expressive than the final stage [38], yet this is not always considered in toolkits.

Addressing the need for exploring temporality, Wald et al. [41] proposed a versatile magnetic platform where users can record the movement of magnets hidden within the device to affect the motion of a soft material being studied, thus emphasizing the material's temporal form. Our toolkit builds on this work by detaching the soft material, in our case a textile, from the horizontal table surface to allow designers to extend possibilities with the textile interface, such as holding or wearing it, to expand the range of possible interactions.

Opportunities through Pneumatics

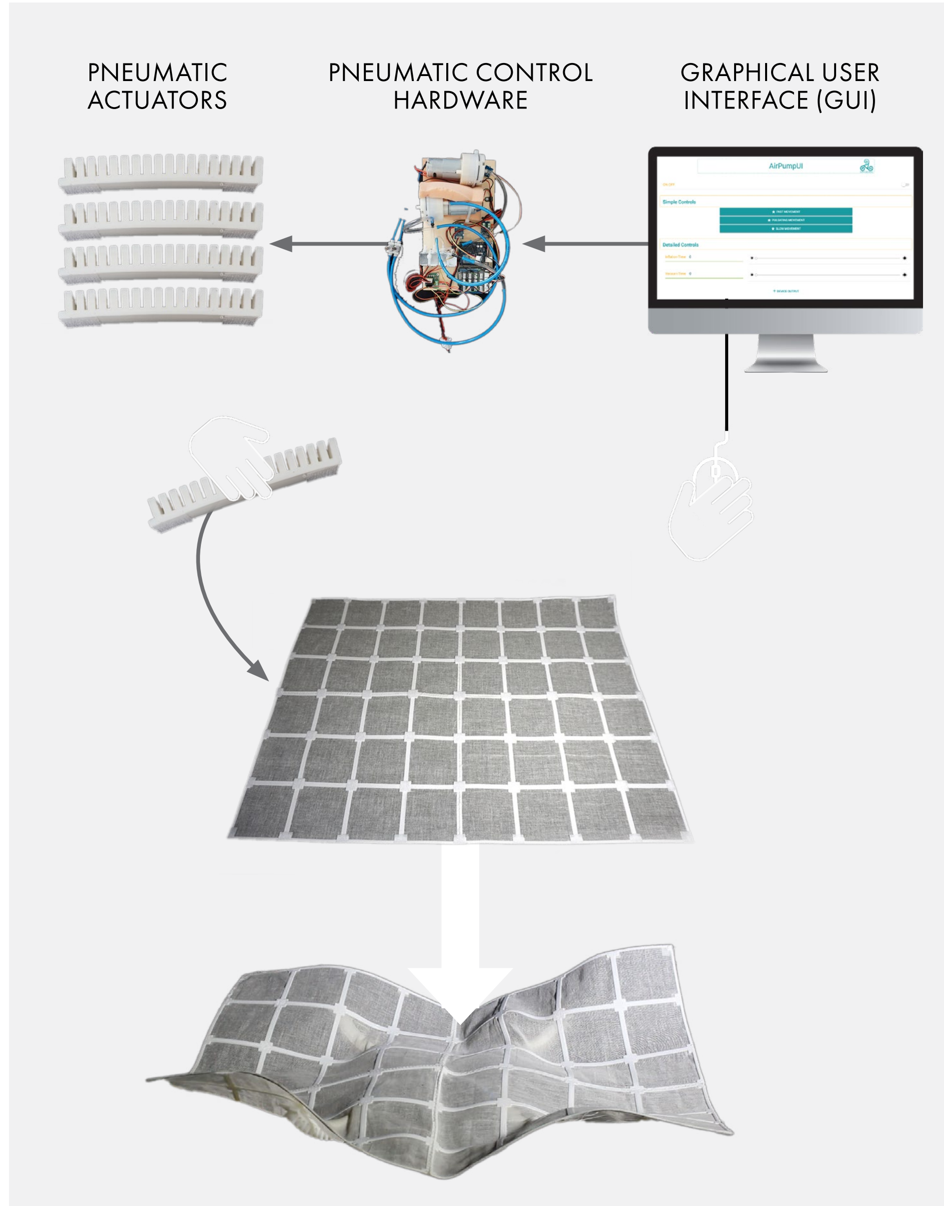
Multiple technologies have been proposed in augmenting textiles with shape change, such as SMAs [6,8], hydrogels [32], and pneumatic actuation [19,42,43]. Many of the proposed technologies have shown to lack reversible movement, precise control over temporal qualities, and difficulty in manufacturability, accessibility, and reproducibility. On the other hand, pneumatic actuation is able to achieve reversible movement and precise control while also being accessible made through the use of readily available material and fabrication processes such as heat sealing fabrics [29], silicone casting [40], and FDM 3D printed actuators [20,44]. The figure on the next page showcases our initial explorations with fabricating pneumatic actuators and 3D printing onto textiles. Pneumatic toolkits have been proposed in the form of novel actuators to augment static objects [26] or to aid in digitally fabricating different shape-changing features [20], yet they lack a medium for interaction and are not focused on exploring temporal expressions. Our toolkit aims to bridge this gap by providing an all-in-one interface to explore temporal expressions in textiles by giving designers control over both the spatial deformation and the temporal changes of the material such as speed of movement and movement duration.

Initial Explorations with
Pneumatics and Textile Systems



THE TEX(alive) TOOLKIT

The TEX(alive) toolkit comprises various physical and digital components working together to provide a range of control over the temporal form of the material. As shown in the figure on the right, the toolkit consists of: the pneumatic actuators, a sample of woven fabric reinforced through 3d printing, the pneumatic control hardware, and the graphical user interface. With this toolkit, designers can explore temporal expressions by connecting the pneumatic actuators to the intersection points across the grid structure in various configurations. The resulting expression can be modified through performative actions with the textile interface such as flipping the textile interface to hide the actuators, holding it in their hands, and wearing it around the body. The TEX(alive) toolkit open-source project can be found here.



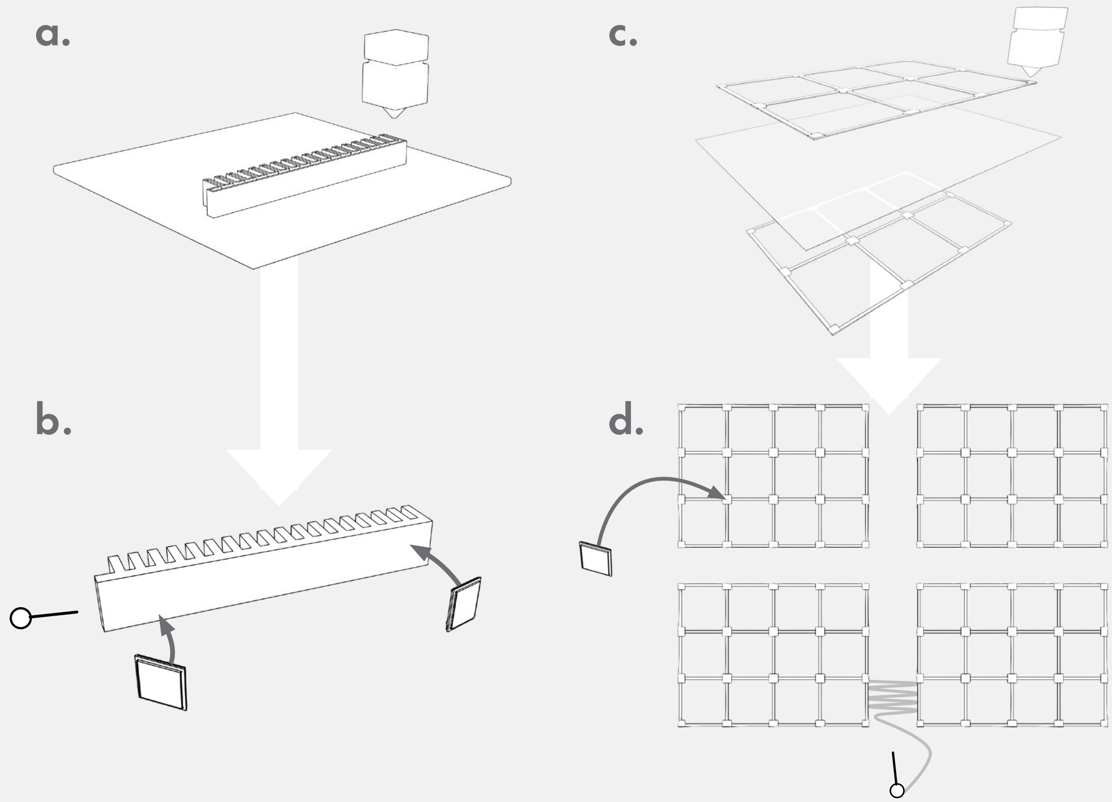
Overview of TEX(alive) Toolkit Components

Pneumatic Actuators

The pneumatic actuators function as the external element that augments the textile interface by inducing shape change. The toolkit uses bending pneumatic actuators inspired by those used in soft robotic hands [33]. Due to the popularity of bending actuators in literature, different fabrication methods were tested such as heat sealing textiles, silicone casting, and 3D printing with flexible materials. Based on the 3D printing settings and parametric designs proposed by the toolkit from [20], 3D printing proved to be an accessible and quick method to produce well-performing actuators. The final actuator design measuring 100x20x13 mm and fabricated with Ninjaflex TPU 85A on an Ultimaker 3 can reach a bending deformation of around 105 degrees at 1 bar of pressure. The fabrication process of the pneumatic actuators can be seen in the figure on the right.

3D Printed Reinforced Textile

The 3D printed reinforced textile functions as the medium of interaction between the shape change and the user. The dynamics of the textile provide the spatial structure needed to communicate the temporal form created by the actuators and the electronics [21]. The textile proposed consists of 100% undyed woven cotton and a 3D printed rectangular grid (Ultimaker TPU 95A printed on Ultimaker 5) printed directly on the textile as a "sandwich" for improved adhesion [11] as shown in the figure on the right. Woven cotton fabric has been shown to have good compatibility and adhesion with various 3D printed materials [30], as was confirmed during our testing using TPU. The rectangular 3D printed grid is a reinforcement to the soft textile to intensify shape changes and provide connection points for the actuators via velcro adhesive. When the actuators are inflated, the textile undergoes a shape change dependent on the location of the actuators.



Fabrication of Pneumatic Actuators and 3D Printed Reinforced Textile

a. 3D print actuator with TPU 85A using custom settings to ensure air tight print.

b. Puncture air inlet hole and attach velcro adhesive at each end.

c. 3D print grid pattern with "sandwich" method: print 3 layers, pause and insert textile, continue printing.

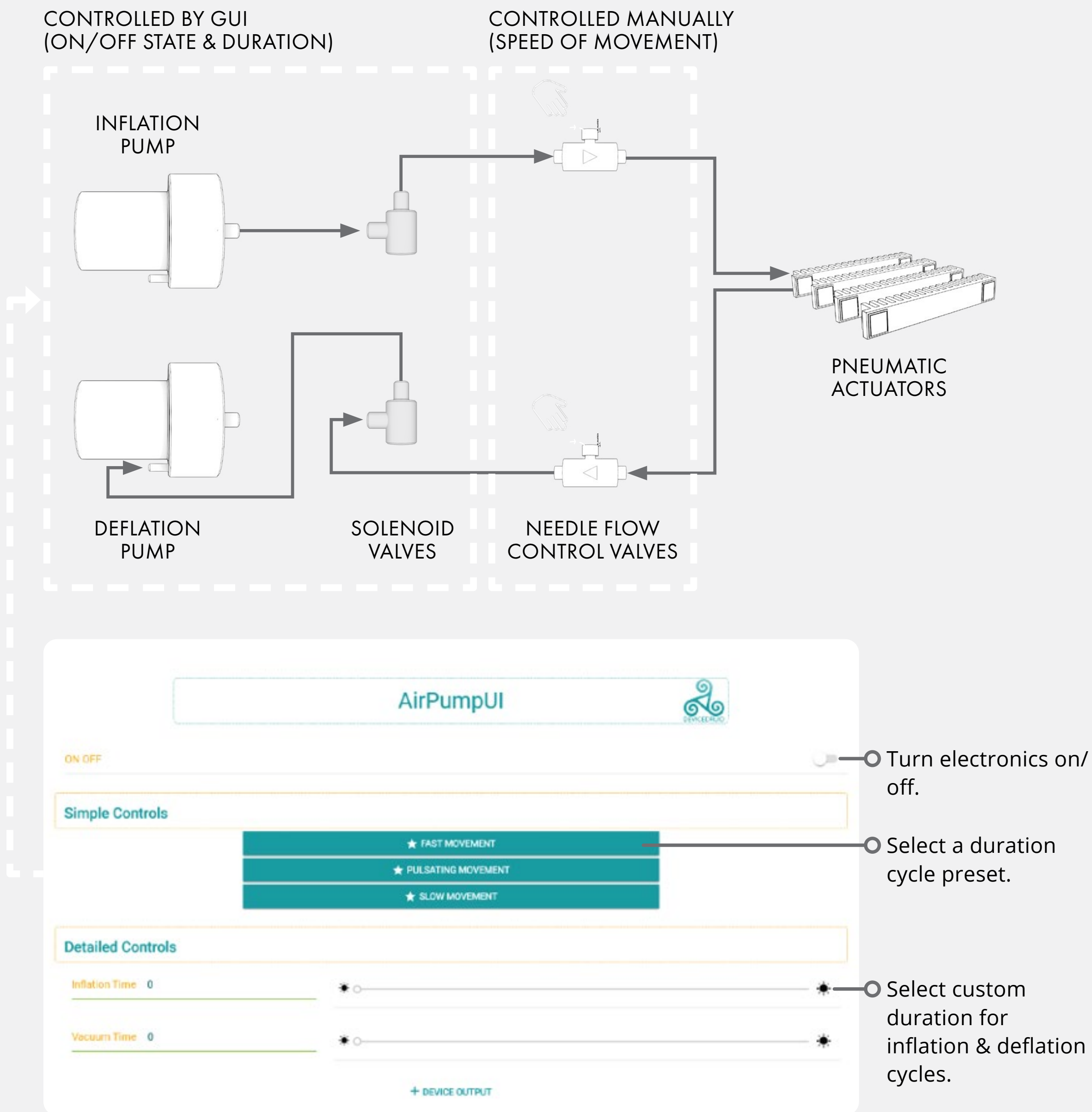
d. Sew multiple samples together to scale up and attach velcro adhesive at each intersection point.

Pneumatic Control Hardware

The accompanying hardware supports the toolkit by providing off-the-shelf electronic components to regulate the air flow going into and out of the actuators, thus affecting the shape-changing qualities. An overview of the hardware can be seen in the figure on the right. The hardware consists of two 24V air pumps, one used to inflate the actuators and the other to deflate the actuators. Each pump is connected to its respective solenoid valve to allow air to flow in a singular direction. An Arduino UNO board and ULN2003 Motor Driver are used for the control of the two air pumps and the two solenoid valves, which can be controlled through the graphical user interface (GUI) to change the on/off state of the pumps and the duration sequence. Two manual, needle flow control valves regulate the airflow rate to the actuators. By manually tuning the needle valves, the user can speed up/slow down the movement of the actuators.

Graphical User Interface (GUI)

The graphical user interface bridges the connection between the actuator/textile interface and the pneumatic control hardware to allow the designer to easily control the material's temporal expressions. The graphical user interface was coded within the Arduino IDE using the plugin DeviceDruid. It gives the user control over the air pump's power state (on/off) and the inflation/deflation duration cycle sequence as shown in the figure on the right. The system runs in a constant loop by alternating between inflation and deflation based on the inputs of the user. By modifying the parameters in the graphical user interface, fine tuning the needle valves to adjust the speed, and varying the location of the actuators on the textile interface, the designer can experiment with temporal forms ranging from quick movements (~1s cycles) to slow growth-like motion (>20s cycles).



Overview of the Pneumatic Control Hardware and the Graphical User Interface

CREATIVE SESSIONS WITH TEX(alive)

We conducted creative sessions with seven designers to explore how the toolkit is mobilized in the exploration of temporal expressions, and identify points for further improvement in our future work.

Set-up

The toolkit was placed in a room on top of a large empty table to allocate space for the participants to experiment. A camera was set up on the table to record the participant's interactions with the toolkit. The audio from the session was recorded for analysis.

Participants

For the creative session, we selected 7 interaction and fashion designers with prior experience in designing with novel interactive materials, in particular smart textiles. We particularly invited these designers to assess the advantages and drawbacks of creating and fine tuning unique expressions using the given toolkit in comparison to their previous material-driven design projects.

Procedure

The session began by introducing the participants to how the physical and digital components of the toolkit are used to control temporal qualities (i.e., speed, duration and degree of change) of the textile interface. Afterwards, they were given time to freely explore the toolkit. Once the designer had a better understanding of using the toolkit, we asked them to set a specific design goal with a temporal expression (e.g., "I'd like to design a carpet which moves like a manta ray"). Then, the designer would proceed to prototype, test, and iterate various temporal expressions to complete their design challenge. They were asked to think aloud through their ideation and interaction with the toolkit. The study was completed with a final discussion on their experience of using the toolkit.

Results

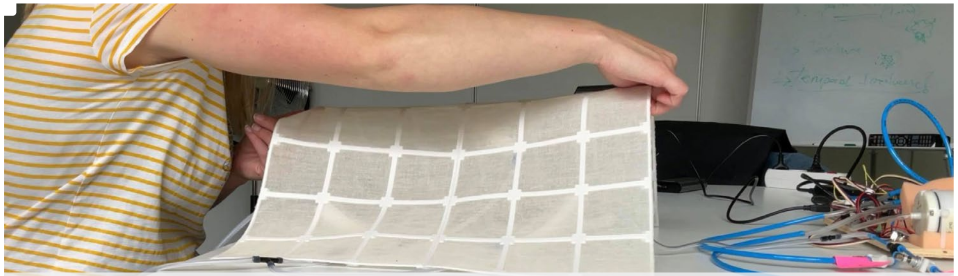
The resulting temporal expressions created for the design goal showed great variation in the expressions and applications possible with the toolkit. The designs ranged from interfaces with living organisms to breathing, adaptable architecture as seen in the figure "Temporal Expressions Prototyped During the Creative Sessions".

Variations in the temporal qualities of the textiles created different interpretations commonly associated with alive-like expressions. Slow movements were associated with growth, cyclic movements with breathing and sleeping, and pulsating movements with animal locomotion and heartbeats. This result goes in line with previous studies, in which rhythmic movements lead to biological interpretations in textile interfaces [38]. The functional applications imagined by some of the participants expanded beyond user interface design to architecture and biodesign.

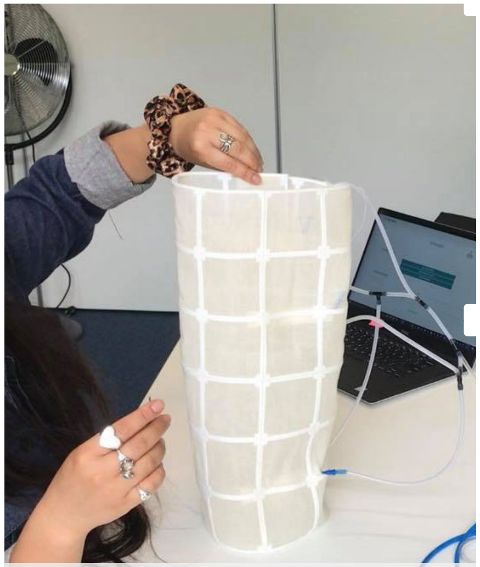
Designers found interacting with the pneumatic actuators and attaching them to the textile interface to be intuitive. They began using simple and symmetrical configurations of the actuators and progressed towards more complex arrangements once the behavior of the textile interface was understood. Additionally, four of the designers in the study expanded the design space with the textile interface from 2D expressions to self-standing 3D forms or application concepts. The figure on this page shows the various ways the designers interacted with TEX(alive) during the creative sessions.

Designers found it simple to turn the system on/off and change the duration of the movement cycles using the graphical user interface. The operation of manually tuning the needle flow valve to adjust the speed of movement created confusion for some participants. Nevertheless, all users successfully achieved their desired temporal expression. In general, all designers expressed the need for such tools to aid in prototyping temporal forms in the interaction design.

Interacting with the 3D spaces created by the shape change.



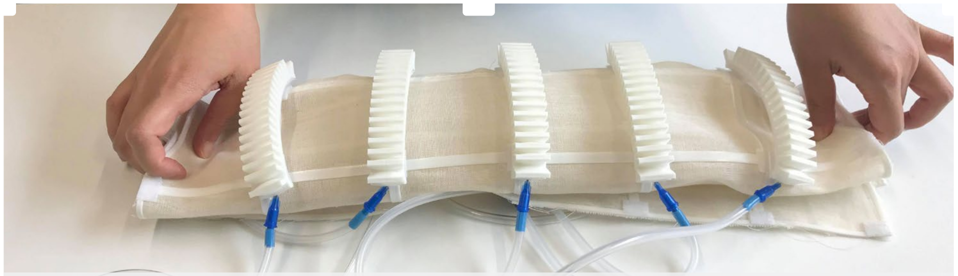
Modifying the spatial initial condition of the textile to change its transient response.



Rolling textile to create 3D volume that expands and contracts.

Brushing the textile to support the growth of a living interface.

Using the actuators as connectors to create a complex 3d surface.



Folding the textile to expose the actuators moving.

Wearing the textile as a garment for haptic interactions.

Temporal Expressions Prototyped During the Creative Sessions

a. **LIVING CARPET** with embedded living organisms that slowly orients itself towards the sun like a flower.

b. **MANTA RAY FABRIC** mimicking the quick, pulsating, wave-like movements of a sea animal to resemble their locomotion underwater.

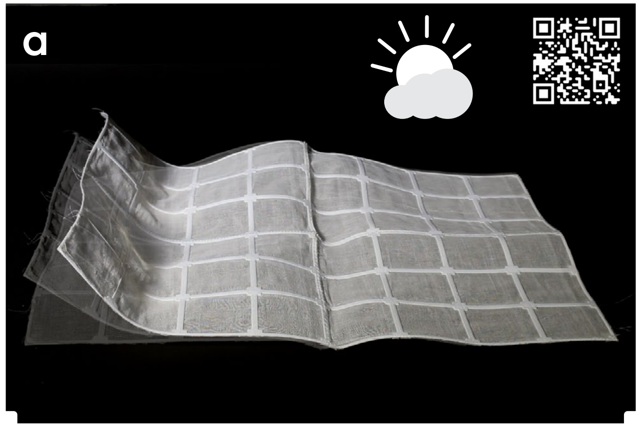
c. **TALKING LAMP** with alive-like qualities following a cyclic breathing pattern while telling stories to the audience.

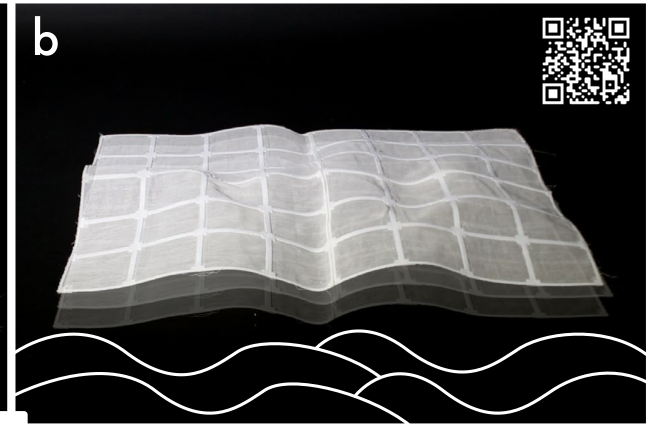
d. **WITHDRAWING FABRIC** expressing stress and relief by slowly curling the edges towards the center of the fabric and quickly releasing the tension at the end.

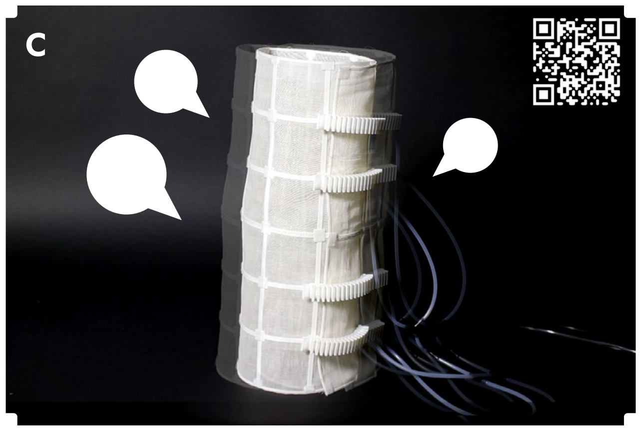
e. **BREATHING CANOPY,** a canopy that would expand and contract to allow pleasant air flow through its structure.

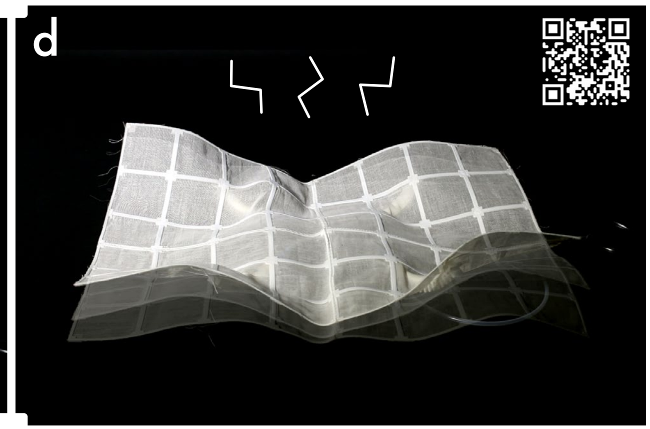
f. **HIDDEN CAVERN,** an interactive architectural exhibit that would open up a passageway for pedestrians to go through as they stepped through the exhibit.

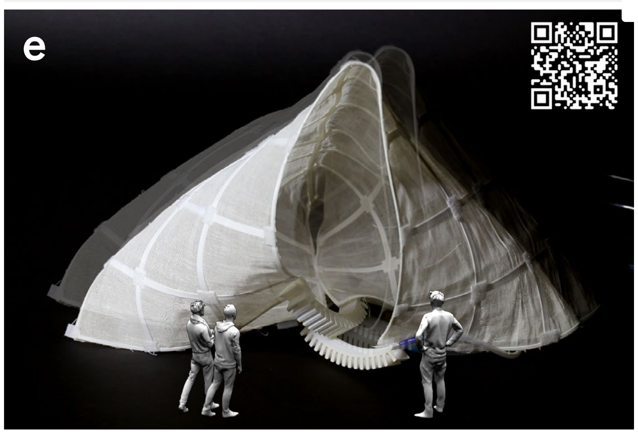
g. **BEATING VEST,** a smart wearable chest garment that helps runners maintain a steady heart rate.

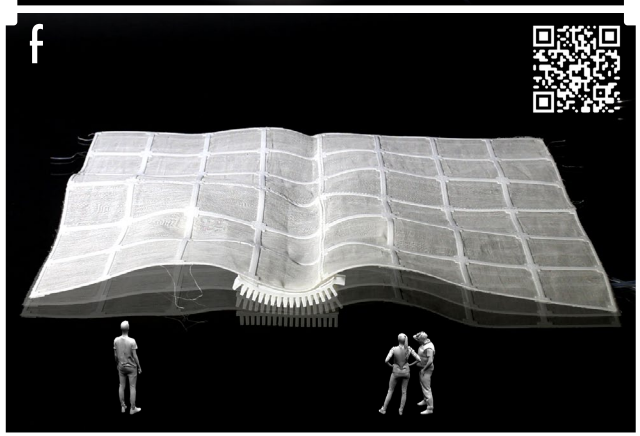


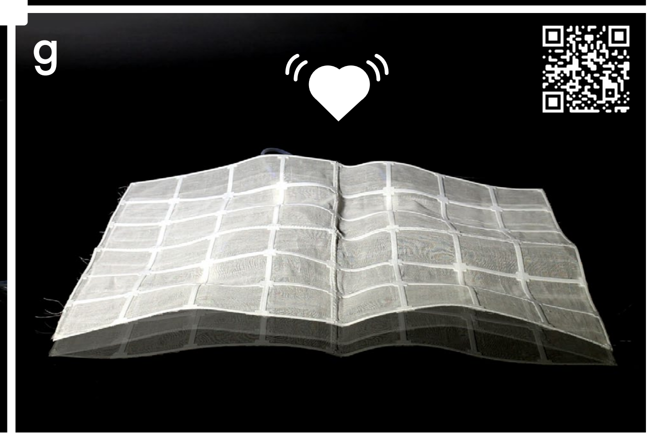












DESIGN CHALLENGES

In this pictorial, we presented TEX(alive), a physical-digital toolkit that helps familiarize designers with the complexity and expressivity of temporal forms in shape-changing textile interfaces. We documented the fabrication methods needed to create the physical and digital elements of the toolkit. Finally, we showed variations of temporal expressions as a result of a creative session with interaction and fashion designers, demonstrating TEX(alive)'s potential for interaction design.

Although the TEX(alive) toolkit proved to aid designers in exploring temporal expressions in a relatively simple and agile manner, several practical limitations still exist for HCI designers. Firstly, the separation of the temporal controls for the duration cycles and speed of movement causes difficulty for first-time users. We recommend integrating the speed controls into the graphical user interface or exploring physical programming tools to be used in place of a computer [37]. Secondly, creating complex expressions, such as a wave-like effect, is challenging due to the current co-dependent behavior of the actuators. To overcome this challenge, we suggest allowing for individual control over the actuators, though keeping in mind that additional control would cause more hardware complexity. Furthermore, this toolkit is designed in a tabletop format which limits the possible unforeseen interactions, for example, requiring assistance to hold the textile on body. We recommend expanding the toolkit with simple props to promote more performative interactions, e.g., bands to tie the textile around body parts and clips to hang the textile on a wall or ceiling.

FUTURE WORK

As we showed in our previous publication, maintaining *textileness* of textile interfaces is essential to fully unlock unforeseen design potentials [7]. In a future version of the toolkit, we intend to replace the pneumatic actuators with a type of actuation that is more integrated in the textile (e.g. Omnifiber [19]) to leverage textile qualities in shape change behavior of such interfaces. Additionally, woven cotton fabric was selected based on its compatibility with 3D printing material TPU, yet the influence of the fabric type on the expressive and temporal qualities of the shape change remains to be explored in future research.

Informal discussions with the seven designers inspired us to further explore the possibilities for a *digital simulation* of the physical interface combining digital and physical workflows in prototyping temporal expressions. The figure below presents our future concept for the workflow of the computational tool (the initial prototype built with Rhino Grasshopper can be found in the open-source project). Such digital coupling of the toolkit would allow designers to expand on their design explorations when the size of the textile interface, thus the complexity of shape-changing behavior increases. With our augmented toolkit, we aim to further inspire HCI and design scholars towards hybrid toolkits in which the *digital twin* of the hardware supports the understanding of temporality in real time with physical and digital manipulation. In our future work, we aim to explore this direction and the overall usability of this hybrid toolkit.

Future Concept of Computational Tool to Predict Spatial Shape Change

a. Actuators are simplified as a folding hinge with controllable folding angle.

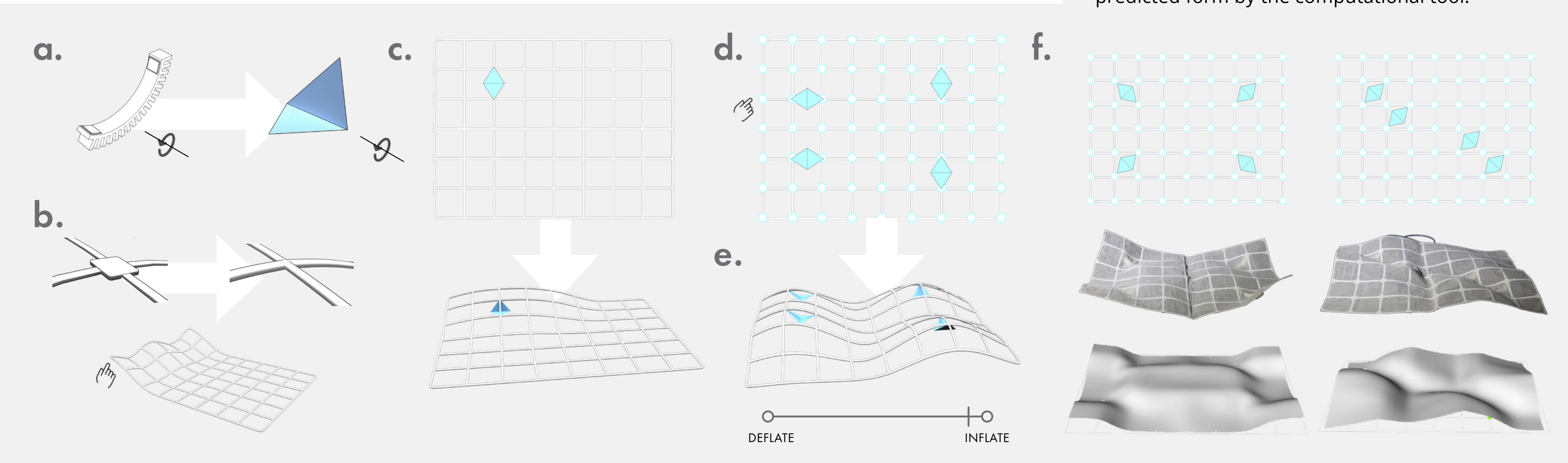
b. Textile is simulated as a flexible mesh. The 3D printed grid is simplified as a bending and stretching resistant rod structure.

c. Hinge endpoints are constraint to the connection points on the textile.

d. Users interactively select endpoints of actuators along textile connection points with the mouse cursor.

e. Actuators can be inflated/deflated (hinge folding angle) by moving the slider.

f. Comparison of the physical prototype and the predicted form by the computational tool.



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