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ABSTRACT

We demonstrate a novel and democratized blow molding technique, PneuFab, enabled by FDM 3D-printed custom structures and temporal triggering methods. Access to computer-aided fabrication tools, such as 3D printing, empowers various craft techniques to democratize the creation of artifacts. To afford new blow molding techniques in the field of Human-Computer Interaction, we make efforts to simplify this challenging handy fabrication and enrich the design space of blow molding by taking advantage of the thermoformability and heat deformability of 3D printed thermoplastics. Showcasing design spaces, including artifacts with complex geometries and tunable stiffness, we hope to expand access and dive into what more the digital blow molding fabrication can be.

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction (HCI)**; • **Interaction devices**;

KEYWORDS

3D Printing, Blow Molding, Hybrid Fabrication, Shape Changing

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1 INTRODUCTION

Fused deposition modeling (FDM) 3D printing, as accessible and additive fabrication technology, has gained a central place in today's making trends, from rapid prototyping [10, 11] to creative expression [13, 17], even building interactive devices [5–7, 15, 18]. Beyond solely for finalized production, 3D printing with smart materials (e.g., biomaterial [21, 22] and thermoplastic [1, 4, 16, 19, 20]) enables shape-changing interfaces in response to environmental triggers. Taking advantage of automatic and semi-automatic custom design in controlling, 3D printing can also serve as an augmented-craft tool to achieve complex aesthetics by lowering the threshold of the craftsmanship [3, 9], which empowers a wide range of possibilities for crafting artifacts. Therefore, we see an opportunity to introduce blow molding techniques that have existed for a long history but not fully been explored in the field of Human-Computer Interaction (HCI) community.

Blow molding can produce hollow structures with large volume, light weight, and complex curvature surfaces, which is widely used in the mass manufacture of plastic [24] and glass [8, 12] for aesthetics or utility. Recently, artists have experimented with customizing blow-molded products using digital tools [2, 14]. However, the limited exploration of controllability and predictability of blowing shape-changing restricts its personalization and democratization. We present PneuFab, a novel and low-cost hybrid fabrication workflow that allows normal users to design and create hollow volumetric shape changes through blowing simple FDM-printed thermoplastic structures. PneuFab programs and prints thermoplastic composite structures as parisons, which can morph into target shapes with thermo-pneumatic triggering. With meticulously designed composite structures, we can fabricate objects with orientational morphing and transformative texture. Beyond the form factors, PneuFab imparts 3D-printed objects with tunable stiffness, ranging from rigid objects to dynamic structures.

2 PNEUFAB FABRICATION WORKFLOW

We design PneuFab composite structure that comprises two types of components in terms of significantly different thicknesses: the

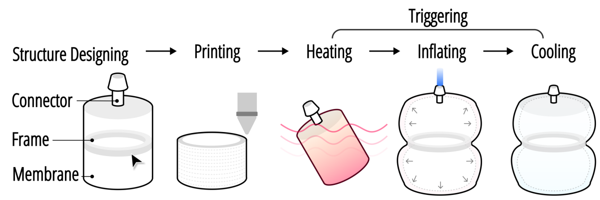

Figure 1: PneuFab fabrication workflow.

membrane and the frame. While the membrane (i.e., the thinner component) tends to be spherical like a balloon with air pressure loaded, the frame is meant to constrain the expansion. Thus, the nonuniform expansion can be leveraged to generate controlled expandable shapes. The fabrication process of PneuFab artifacts occurs in 3 stages: 1) designing a parison with our simulation tool, 2) 3D printing the inflatable structure, and 3) blow molding artifacts with thermo-pneumatic triggering (Figure 1).

3 TRIGGERING TECHNIQUES

Leveraging the heat transference lag between thermoplastics of various thicknesses, we further design a set of thermo-pneumatic triggering methods. Inspired by the shape-changing principle of prior work [23], we leverage the thermal lag which is due to the significant difference in thickness between the membrane and the frame to control the shape changing. We control the inflated shape by adjusting heating times and alternating the heating, inflating, and cooling processes. To clearly demonstrate the workflow of PneuFab triggering method, we assume a significant thermal lag between the frame and the membrane and denote their expansion starting time as t_m and t_f in a water bath environment. After the thermoplastic is heated thoroughly, we inflate the parison using an electric vacuum pump for inflating and a 3-way solenoid valve which is controlled by an Arduino board. When target shapes are achieved, we can simply leave them at room temperature with constant internal pressure to cool down or submerge them into cold water for quicker cooling. As shown in Figure 2, we demonstrate how multi-phase shape-changings with significantly different results are achieved with the step-by-step workflow.

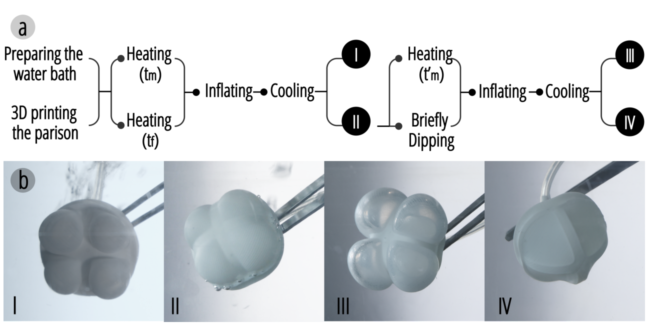

Figure 2: (a) Temporal triggering process and techniques with four phases; (b) Physical fabrication results in four phases.

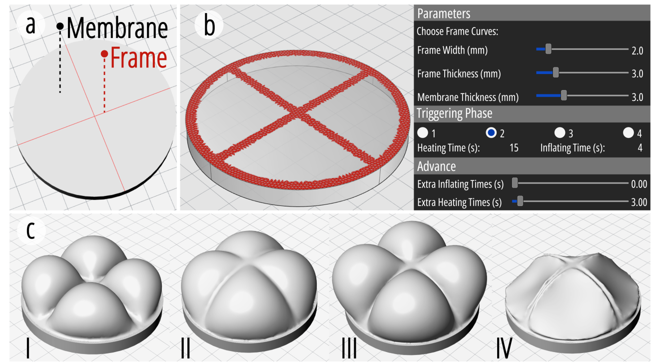

Figure 3: User interface workflow: (a) drawing curves as the frame on the selected basic model as membrane; (b) structure geometry customization; (c) simulation with selected triggering phase.

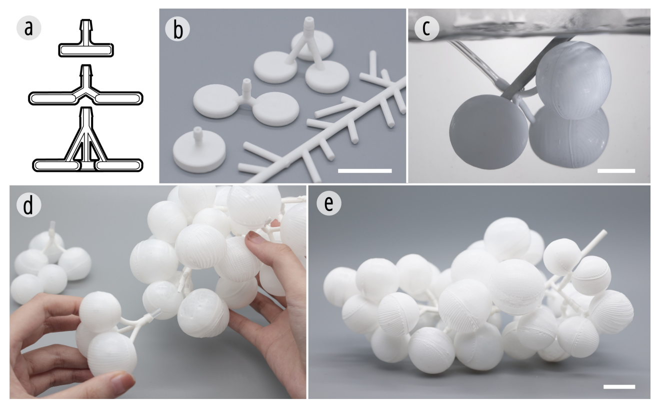

Figure 4: (a) Structures of grapes; (b) Printed grapes modules and stem; (c) Triggering process; (d) Assembly process; (e) A sculpture of grapes. Scale bar: 20 mm.

4 USER INTERFACE

To help users understand PneuFab workflow and support design iteration, we developed a parametric design tool, with which users can program the target shape of the inflatable structure by manipulating geometry parameters (Figure 3). The visualized simulation of chosen triggering methods facilitates the design iteration. Finally, a model for 3D printing and practical instructions for physical triggering can be generated based on the previously user-defined parameters.

5 BLOW MOLDING ARTIFACTS

To illustrate the potential of PneuFab technique for creative expression, prototyping, and tangible interaction, we designed and created several artifacts in application domains: sculptures, jewelry, illuminations, and haptic devices.

5.1 Modular Sculpture

Modular Design for Grapes. To illustrate PneuFab's ability to complement 3D printing, we created a bunch of grapes by means of modular assembly (Figure 4). While the grape stem can be easily printed in a planar shape with the conventional FDM method, printing spherical grape berries is challenging for FDM printers, which require plenty of supporting structures and may end up with rough surfaces. Therefore, we designed the grape berry modular with PneuFab method. After all the prints are ready, we inflate all the berries and connect them to the stem.

Modular Designed Balloon Dog. We inflated a balloon dog sculpture, a common figure in balloon art (Figure 5). The design consists of two units: three pairs of parallel balloons for ears and legs and four units of balloons in a folded shape for the head and body. The compact design also saves space for packaging and transporting.

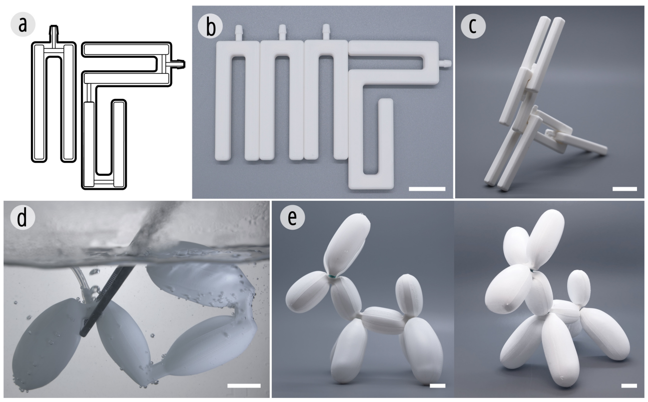

Figure 5: (a) Two modular structures of balloon dog; (b) Printed modules; (c) Preview before triggering; (d) Triggering process; (e) A sculpture of balloon dog. Scale bar: 20 mm.

5.2 Jewelry Design

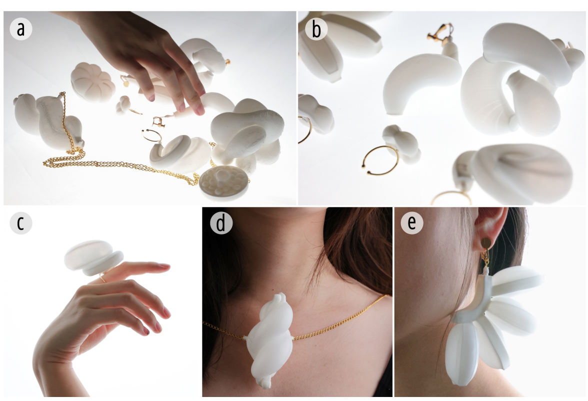

Figure 6: (a, b) PneuFab jewelry on display; (c) A ring; (d) A necklace; (e) An ear pendant.

The PneuFab artifacts are lightweight organic and unique shapes with only a few grams. From opaque to translucent, the pleasing waxy texture, alluring roundedness, and radiance were what makes them ideal for use as jewelry (Figure 6). We hope PneuFab can facilitate the fabrication of wearables and inspire design in the DIY community.

5.3 Ambient Lights

Lampshades are generally large and fragile, which take up much storage space and are inconvenient for transportation. PneuFab provides designers and artists with a new method for producing illuminations. In this application, we show how PneuFab innovates illumination design with transformative shapes and delicate textures (Figure 7).

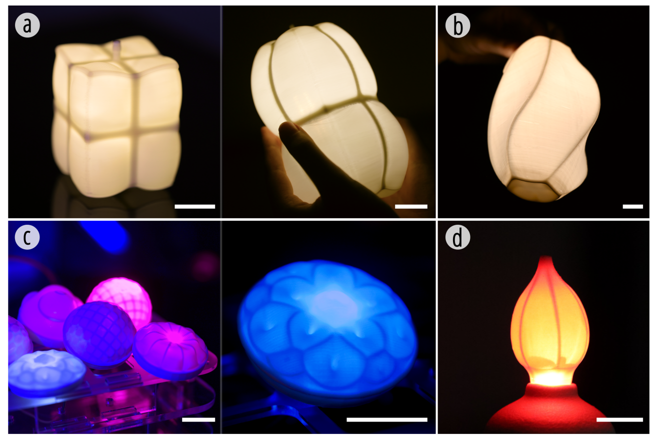

Figure 7: (a) Transformative lamp; (b) A lantern; (c) Ambient lights with various textures; (d) Campfire light. Scale bar: 20 mm.

5.4 Tangible Devices

Leveraging the flexibility and tunable stiffness of thermoplastic artifacts made with PneuFab, we can create devices for tangible interaction.

Pneumatic Keyboard. We fabricated the pneumatic buttons in one piece with homogenous material by designing concentric planer structures. By connecting them to pressure sensors, information can be input when we interact with PneuFab keyboards (Figure 8).

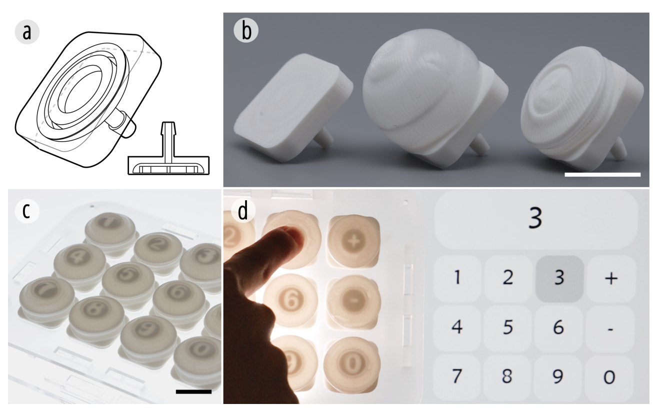

Figure 8: (a) Structure of a button unit; (b) Transformation process for making a button; (c) Assembled keyboard; (d) Keyboard input for a calculator. Scale bar: 20mm.

Pneumatic Joystick. Similarly, we designed a pneumatic joystick structure with tunable stiffness, as shown in Figure 9. The as-printed parison of the joystick is designed in a cylinder shape, and the quadrature points of the frame curves are shifted up and down to contact the adjacent ones. The fabricated piece is like a spring for pressing, stretching, and bending at all degrees of freedom.

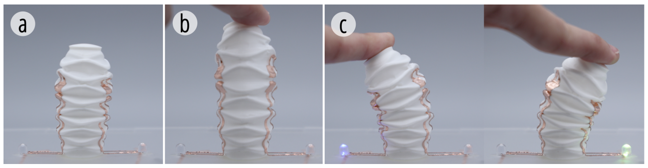

Figure 9: (a) PneuFab joystick; (b) A deactivated joystick with internal air pressure; (c) Pushing the joystick to light up LEDs.

6 CONCLUSION

We present PneuFab as a novel hybrid fabrication technique which combines the advantages of 3D printing and blow molding for making artifacts with complex geometries and haptic properties. We meticulously design composite geometry structures and apply controllable trigger techniques. We demonstrate the potential of PneuFab, from decorative sculptures to interactive devices. We also propose an instructive design tool to facilitate the iterative design with visualized simulation. As a democratized method, PneuFab hopes to inspire and invite creative expression to push beyond the boundary of 3D printing.

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