Early Explorations of Deformable Interactive Designs with 3D-Printed Springs

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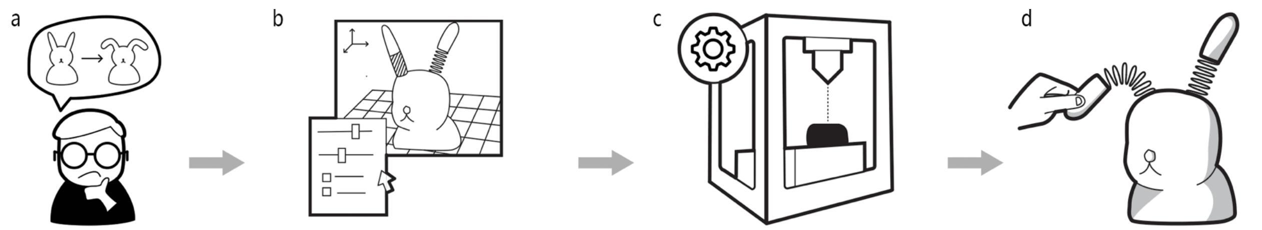

Figure 1: Proposed workflow of making deformable 3D-printed objects – (a) ideating possible deformation behaviors; (b) designing and simulating deformable parts in our CAD tool; (c) fabricating with modified g-code and printer; (d) validating in the real world.

ABSTRACT

We propose a tool-based workflow that allows novice users to create deformable 3D-printed objects with embedded spring structures. In our early exploration, we investigated possible deformation behaviors, implemented a GUI-based computational tool, and made minor modifications to a commodity 3D printer to support spring printing. The goal of this poster is to describe our research vision and share our early results with the computational fabrication community.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction**

KEYWORDS

3D printing, CAD tools, computational fabrication, embedded mechanical springs

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1 INTRODUCTION

Traditional 3D-printed objects are rigid and non-interactive. Recent work has explored a wide variety of approaches to address this, including multi-material design [Bickel et al. 2010], soft fabric [Peng et al. 2015], embedded patterns [Iwafune et al. 2016], and mechanical metamaterials [Ion et al. 2016]. In our research, we are exploring a new tool-based workflow to support novice users in creating interactive, deformable 3D-printed objects using embedded *spring structures*. Our proposed workflow involves both specialized software and hardware to *design*, *simulate*, *fabricate*, and *validate* a set of possible interactive deformation behaviors using mechanical spring theory [Budynas et al. 2005] (Figure 1). In this pipeline, we envision that users can (i) define desired deformations and embed suggested springs into 3D designs through a direct manipulation interface; (ii) preview the simulated deformation and iterate their design interactively; and (iii) print their design on a consumer-grade 3D printer with only minor modifications (modified g-code and an auxiliary cooling system).

2 CURRENT TOOL

We have focused on three areas thus far: (i) exploring the space of possible deformations based on spring theory and the limits of additive manufacturing; (ii) building a CAD software plugin that embeds springs in 3D models; and (iii) creating a modified printing method to fabricate output from our CAD tool (*i.e.,* embedding springs).

2.1 Deformable Design Space

Informed by prior work [Ion et al. 2016, Iwafune et al. 2016] and spring theory, we propose four major deformation behaviors based on the physical properties of two types of springs, helical and cantilevered flexure: *stretching* and *compressing (helical springs)*, *twisting (cantilevered springs)*, *bending (both)*, and *scaling (both).* Each deformation type entails certain spring parameters including coil number, coil diameter, wire diameter, modulus of elasticity (helical spring), beam number, and length (cantilevered springs). An embedded spring's length and distribution depends on the part geometry it replaces. These mechanical features are parameterized in our tool, described next.

2.2 Computational Design Tool

To support the ability to embed springs and edit the desired deformation, we implemented a GUI-based plugin for Rhinoceros, a professional-grade CAD tool. The current plugin supports the selection of a 3D part, the generation of both types of springs, and the real-time rendering in CAD scenes. In the future, rather than designing springs through parameter specification, users will also be able to specify deformation behaviors (*e.g.,* bending or stretching) and see resultant spring designs automatically that fit within a part's geometry.

2.3 Modified Printing Method

Making spring-embedded objects with off-the-shelf printers is difficult because, by their very nature, springs deform when loaded during printing and can break when removing support material. To address these problems, we changed the extrusion feed rate, compensated for vertical deformation in our generated g-code, and added external cooling to the extruder of a Printrbot Simple with brass tubing and an external air compressor.

3 RESULTS AND FUTURE WORK

In our initial tests, we were able to parameterize and print a variety of spring designs using our approach and manually retrofit rigid objects with deformable shapes; however, we have not yet successfully printed a complex 3D object with embedded springs (such as that shown in Figure 1). Through our tests, we have also confirmed that the embedded springs deform due to the weight of subsequent additive layers, as expected. Our tool must appropriately estimate this load and account for these deformations in the spring design preview and printing process. Additionally, in practice, a certain amount of support material is still necessary to successfully print parts on top of springs. We are working on a fully interactive design tool including simulations and hardware optimizations for a more robust fabrication process. We look forward to sharing this early work and receiving critical feedback from the computational fabrication community.

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