Growing Interactive Mushrooms: Form Finding for the Generative Design of 3D Printable Electronics

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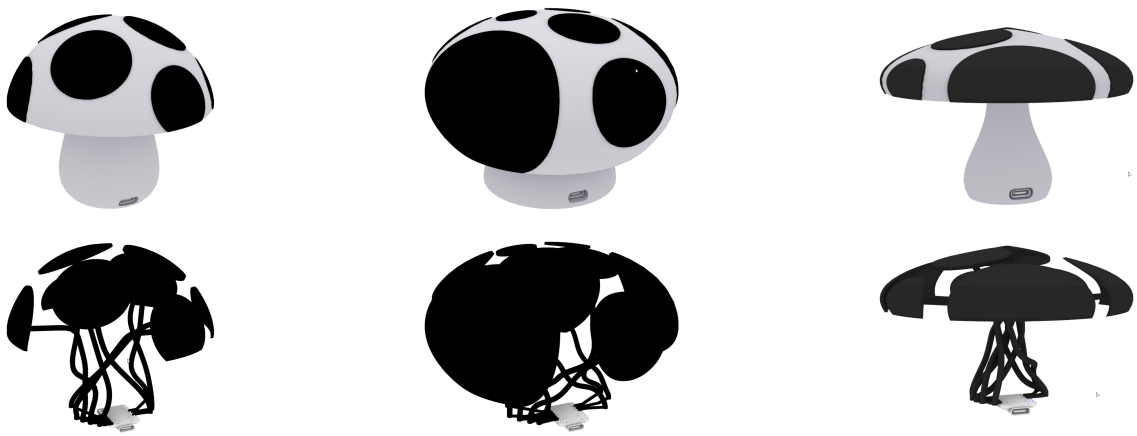

Figure 1: Generative *TuneShrooms* are capacitive touch instruments designed with form-finding algorithms.

Abstract

In this Lighting Talk, we will present an approach to enable the fabrication of generative interactive objects. The process builds on our work called *Pintegrated Circuits* which enables rapid customisation of 3D printable interactive objects which incorporate printed circuit boards (PCBs). We combine the fabrication of fully enclosed electronics with the development of a novel technique for automatic routing. Our specific demonstration supports the automatic fabrication of 3D printed TuneShrooms – mushroom-shaped capacitive touch MIDI instruments. Through this design and the accompanying talk we will demonstrate the development of a domain-specific design tool and algorithm for the fabrication of interactive objects using tools and materials readily available to designers and makers, suggesting future application in bespoke interactive device production in non-industrial contexts. Using Kangaroo Physics, a Package for Grasshopper3D, an implementation of our platform automates the routing of non-intersecting conductive traces through arbitrary predefined 3D meshes.

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1 Introduction

Interactive device fabrication is increasingly material-centric, as digital fabrication tools support makers to add functionality into the structure and materials of the device itself [3, 4, 7]. Low-cost and increasingly accessible prototyping tools allow designers and makers to harness the precision of machines to craft functional objects in non-industrial settings. Specifically, 3D printed electronics using fused filament fabrication (FFF) is a well-explored avenue of research which is becoming part of the tool-belt of designers [1, 6, 9].

Despite the availability of physical equipment and materials that support fabrication 3D printed interactive devices. Specific design tools for 3D and structural electronics are not accessible, and design

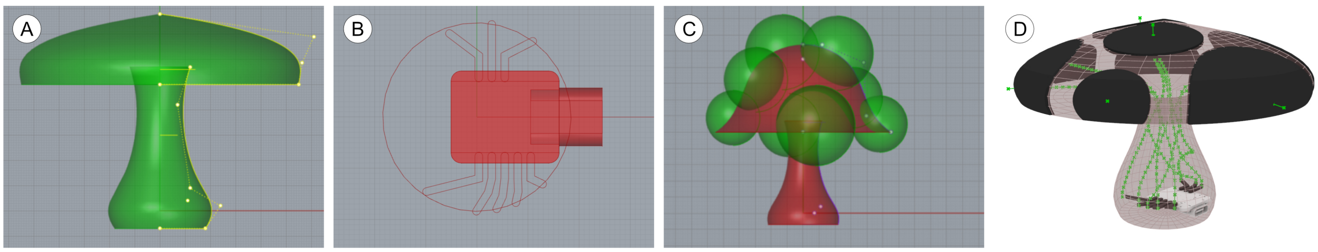

Figure 2: Automated stages of TuneShroom design: (A) User specified curves create a solid of rotation. The user places a PCB from the library into the design and physics based form-finding is used to (B) fan out the wires on the base plane, (C) position non-overlapping touch pads on the cap, (D) Route traces from the contact points to the touch pads.

must therefore be done in either existing electronic or mechanical CAD platforms, giving up crucial capabilities of the other. Attempts to create tools that support material-centred interactive device fabrication have been made, such as Capricate [9] and Pipedream [8] which provide automatic routing between interactive elements and connections to more conventional electronics. However, adaption or integration into modern design tools has been slow, and as electronics becomes more integrated into the devices themselves avenues to adoption become critical.

These approaches introduce additional workflow steps within standard digital fabrication processes. The increasing breadth of expertise required to engage with these technologies forms a barrier to adoption and interaction.

In this project we take a different approach. We create a domain-specific design tool as a demonstration of what we imagine future bespoke interactive process may be like. Instead of creating a general purpose tool or building functionality into an existing model we present the TuneShroom customizer as a stand alone parametric platform that allows individuals to customize and create their own interactive mushroom-shaped musical instruments. Our process is nonetheless modular so stages of our platform could be reused across a wide range of designs.

This approach leans on patterns from traditional passive 3D printing, where online customizers allow non-experts and experts alike to re-use designs and modify specific parameters [5]. This creates an entry point for newcomers to engage with customisable material-centered interactive device fabrication without the need to become an expert across the domains of mechanical and electrical design.

In this work we demonstrate a our tool for the design of custom interactive *TuneShrooms.* The *TuneShroom*, presented in figure 3 was designed as an example to demonstrate the Printegrated Circuits process. In this piece and lightning talk we will present how that design was taken from the one-off manually designed prototype to a customizable design with in-built automated routing and contact placement. The process harnesses physics form-finding simulations to integrate design rules within the model itself, allowing for a wide range of forms while maintaining electrical functionality.

2 Parametric TuneShrooms

In this section, we outline our development of a customizer for parametric TuneShrooms, illustrating a transferable method for integrating electronics and facilitating the automatic routing of conductive traces within 3D models.

The design tool is structured as a Grasshopper3D definition, leveraging the form-finding capabilities of Kangaroo Physics. This enables the creation of non-intersecting pathways throughout the model, allowing for efficient passage of conductive materials, such as carbon-infused PLA.

2.1 Design

2.1.1 3D form. The fundamental geometric shape of the mushroom is derived from a pair of curves referenced from the Rhino CAD modeling environment. These curves are used to create solids of revolution that define both the base and the cap of the mushroom, guiding the entire form-finding process. By manipulating the control points of these 2D curves within Rhino, different mushroom forms can be easily created.

2.1.2 Embedded electronics. A library of 3D models of embeddable printed circuit boards was created. Each file contains both the geometric form of the PCB as well as details of the cavity needed to support it within the print and lines that represent where they are on the board. All PCBs in the Printegrated Circuits process must be placed unpopulated face up [2], so inserted PCBs can be described by a single point. The cavity for the PCB and the input USB to the PCB is subtracted from the original base model mesh.

2.1.3 Fan-out. The highest density of conductive traces in our model is where the conductive traces fan out from the contact pads of the PCB. Traces need to be thinner at this point to fit them in and avoid intersection. Thinner traces are more resistive, so we fan out these points in the plane of the top face of the PCB, and then, in a later step, add the thicker traces that travel through the print. Traces from the pads of the PCB must be 1.5mm wide to allow for a 1mm gap between adjacent pins (standard pin spacing in PCBs). These first fan out as parallel lines from the PCB then expand out at different angles and increase the size of the base of the conductive tubes. This 2-dimensional fan pattern depicted in Figure 2 is created using a simulation similar to the later 3D routing where traces extend outwards from the anchored contact points, and uses collision detection to avoid overlapping traces.

2.1.4 Touch pad population. The spots on the top of the TuneShroom are capacitive touch pads, which serve as the input interface. To enhance customisation options, these pads can have adjustable sizes and positions. In our design, we populate the top surface of the PCB with eight pads of varying sizes and placements. The pads are defined by the intersection of spheres with the cap, with their centres located at specific points on the surface. To ensure that the pads do not overlap, we utilise an additional solver component with objectives that guarantee the points remain on the surface and that spheres with radii larger than those of the pads come into contact with one another.

2.1.5 Automatic routing. Finally, demonstrated in Figure 2 D, automatic routing between the fanned-out contact points and the touch pads on the mushroom cap is performed using a more complex kangaroo solver definition. 1. A chain of line segments is constructed between the points on the fanned-out pieces, then points are populated along those lines. 2. The solver takes the hard anchor constraint to maintain the position of the end points 3. An inset version of the mushroom geometry is used to create a boundary within which the line segments must remain. 4. The line segment chain uses the rod, collision, and solid goals to ensure line segments maintain a minimum distance from each other, create broad sweeping patterns and stay within the mushroom geometry 5. The polyline defined by the line segments is used to define a pipe to go from the contacts to the capacitive touch pads

Finally, the conductive pieces are subtracted from the original model to create a separate body for the non-conductive form and each of the touch-pad-trace-contact combinations.

3 Discussion and Future Work

Modelling interactive objects can be a significant barrier to adoption and experimentation with these tools, as it necessitates the integration of a wide range of skills and expertise. In developing this interactive device customiser, our proposed approach automates much of the tedious work involved in creating these devices and integrates design expertise into the workflow.

In this vein, we focus on projects like *Dynamic Toolchains* by Twigg-Smith and Peek [10], which enable novel workflows and designs that support extensibility and iteration. In future work, we aim to explore how both experts and non-experts might create and develop interactive devices where more complex design constraints can be directly integrated into the objects themselves.

4 Conclusion

We have presented the generative *TuneShroom*, a novel way of supporting the customisation of interactive 3D printable objects. Using form-finding techniques and parametric design, we integrated mechanical, electrical and aesthetic constraints into a customisable design. Through this approach, we highlighted challenges preventing the adoption of 3D printed electronics for high-fidelity interactive device creation by non-experts.

Figure 3: The original 3D printed interactive TuneShroom

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