# Print and Place Isotyping Board

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***Abstract*—Print and Place uses everyday FDM 3D printing techniques to rapidly fabricate at low volume, high fidelity and reproducible interactive hardware. Using multi-material printers with conductive and non-conductive filament, we embed traditional PCB based electronics within fabricated parts to make functional electronic prints. This is achieved by inserting custom G-Code during slicing to both pause the printer for manual electronic part insertion as well as perform injection movements to secure them mechanically and electrically to the rest of the part. We propose the concept of an isotyping board, a general purpose microcontroller based board that can be integrated within printed parts that can be used in the context of low-volume production runs and part customisation. The Print and Place approach means that makers and prosumers can rapidly iterate and locally produce designs closer to the production stage, enabling customizability of electronic interfaces while maintaining the sturdiness and appearance of 3D printed parts.***

## I. Introduction

Interactive hardware creation is challenged between the stages of crafting one or two prototypes, and taking that concept to production [18]. This inertia truncates the market for niche interactive devices which may be genuinely useful to smaller groups and communities of users [12]. Research has identified the importance of solutions which support low volume and organic scaling of manufacturing [29]. Hodges and Fraser discuss the need for a new generation of tools and techniques that scale from prototypes towards products [13], where a concept that sits between a prototype and a mass-produced product has come to be known as an *Isotype* [1].

In this paper we describe the *Print and Place* process, and present an example of an *Isotyping Board* to be used alongside the 3D printing process to rapidly produce variations or isotypes of interactive hardware.

## II. Related Work

In HCI, personal fabrication technologies promise to enable local manufacturing of digitally shared physical objects using tools that embed domain specific knowledge [3].

### A. *Printed electronics for personal fabrication*

Two-dimensional and three-dimensional printed electronics are prominent fields of research which have developed a range of direct write technologies as fabrication tools that promise simple local production of one-off devices. Kawahara et al. present *Instant Inkjet Circuits* [17] which make use of consumer inkjet printers with silver nano particle ink cartridges to create custom paper and PET film based circuits. Components are connected to the circuit traces with anisotropic conductive film. A number of other researchers have explored making circuits on flat substrates using carbon black based paints [25], vinyl cutting conductive foil [22], and using stickers containing electronic components [14].

Within the realm of 3D printed electronics, projects like *PrintPut* [4] and *Capricate* [23] offer a pipeline to add conductive traces and capacitive touch pads to plastic FDM printed parts. Hanton et al. present *Protospray* [9] which uses conductive filament in order to print custom curved displays.

These works and related projects provide insight into opportunities to align FDM printing with personal fabrication, but in order for the technology to become more widespread, a key challenge is robust connections between printed and conventional electronics [8]. While some projects like *ModElec* [11] and the *Voxel8* project [30] focus on individual component interconnection, these technologies rely on low resistance conductive traces which can only be achieved with highly specialised 3D printers. *Oh Snap!* [24] uses magnets and pogo pins to connect 3D printed conductive traces to a PCB. This approach seeks to seamlessly couple electronics to boards, and moves towards direct integration of conventional electronics into printed electronics.

### B. *Beyond prototyping boards*

Prototyping boards such as the *.Net Gadgeteer* [27] , *Arduino* [31], *Flora* [15], *BBC micro:bit* [2] and others [19] have lowered the barrier to entry to conventional electronics prototyping. Boards for material focused prototypes such as the *MakeyMakey* [5] and Bare Conductive *Touch Board* [32] are designed specifically to interface with unconventional electronic interfaces. However, the means of connection between board and material are still basic and don't offer a clear route from prototype to production.

Systems like *Jacdac* [6] are designed to support transitions from prototype to product with projects like *MakeDevice* [10] by streamlining the board and enclosure design process. Commercial platforms also provide tools for connecting or redesigning microcontroller-based products and regularly make their hardware open source for users to use the boards as reference designs for their own projects. *The Raspberry Pi Compute Module* [20] offers hardware designers an approach to use pre-packaged control hardware in their products that has already undergone extensive functional and compliance testing, offloading a portion of this responsibility from the maker.

## III. Print and Place Process

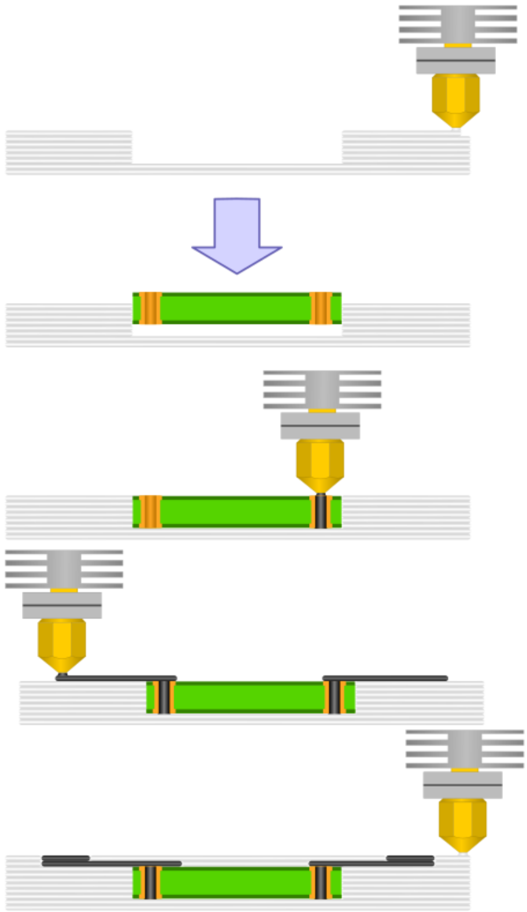

Fig. 1. The Print and Place process, from top to bottom: non-conductive material is deposited with space for PCB, print is paused and PCB is placed, Custom GCode commands are used to inject conductive filament into plated though-holes, conductive filament is used to print traces and pads for capacitive touch sensing. Non-conductive filament is used to insulate traces.

Print and Place allows for the insertion of conventional control electronics into multi material 3D prints that use conductive and non-conductive filament creating a combined functional device. Using the design files of the inserted board, we can design aligned electronic features on the printed device as well as generate specific G-Code to inject conductive plastic into the plated though holes of the electronic part and form robust mechanical and electrical connections. With the open source EDA tool KiCad, we export the coordinates of the drill holes and graphics files for the board outline. Loading these into a 3D CAD software allows us to create the rest of the physical and functional design. After slicing the final model for 3D printing, we run a post-processing script that inserts a pause command to the GCode on the layer where the user should manually insert the part, and after this, add instructions for the nozzle to lower itself above all of the plated though holes and inject a precise amount of conductive filament to fill the hole.

For these examples we use a generic white PLA for the insulating plastic and *Protopasta Electrically Conductive Composite PLA* [33] for the conductive traces. While the resistance of this filament Is still high, 2.5-3.5 kohm across a 10cm stretch of un-extruded 1.75mm filament, it still can be used for capacitive touch sensing. It has also been shown to work as a rear electrode in electroluminescent displays [9].

So far, we have only been using it yo fabricating devices with built in capacitive touch sensors, but hope to explore other functional methods.

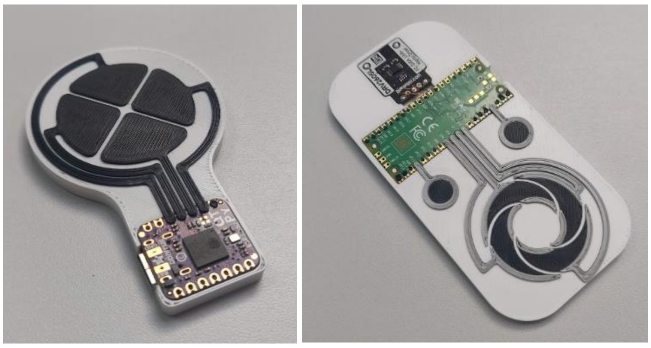

Fig. 2. Print and Place prototypes with existing development boards. Left Adafruit QT PY ESP32-S2, right Raspberry Pi Pico + Linear haptic actuator module.

## IV. Isotyping Board Prototype

The idea of the isotyping board is to design a PCB specifically for the Print and Place process, but which is generalisable to many different product designs. At this initial stage, we want to explore capacitive touch using self-capacitance sensing [7] and haptic feedback with Linear Resonant Actuators (LRAs).

While experimenting with this process, we have only used existing prototyping boards. The two examples we present use an *Adafruit QT PY ESP32-S2* [16] and the other uses a *Raspberry Pi Pico* [34] along with a *Pimoroni Linear Actuator Haptic Breakout* [35] which are soldered together via thin magnet wire, because the conductive filament has too high a resistance to power the actuator.

While these examples provide a proof of concept, it's clear that all control functionality that must be on a PCB should be on the same device, and there are various design decisions about placement of components that might be made differently when making a board specialised to the process.

We have designed a board that combines the control with an RP2040 microcontroller, and a haptic linear actuator and driver. We plan to use this approach to create a number of demonstrations of touch and haptic interfaces.

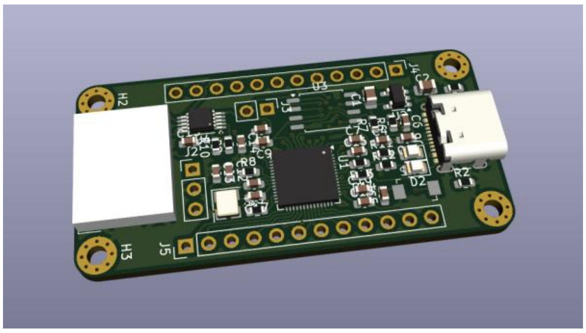

Fig. 3. Render of first print and place isotyping board

## V. Future Examples

We are currently focusing on the haptic-capacitive touch example isotyping board, but we imagine implementing a number of other isotyping boards, including:

- A board with a capacitive touch matrix controller to be used to create non-planar touch surfaces.
- A lighting controller which combines LEDs on a main board, but allows for different shaped lamps to be designed around a main base.
- A modular synthesizer base board that combines logic with digital signal processing logic, but allows for completely reconfigurable control surfaces with re-writable firmware.

Furthermore, we hope to explore how, once settled on a design of isotyping board, we can produce them at scale, with reliable firmware, suitable testing and being fully compliant so that anybody could use such a device in their own product.

## VI. Responsible innovation

We accept that embedding electronics into plastics is environmentally unfriendly. However, we have also demonstrated that it is possible and even easy to recover boards from printed parts with the use of a heat-gun at a low temperature to free the re-usable boards from the printed body. By focusing on making general control electronics around reconfigurable interfaces, we expect a low number of wasted boards because they can easily be used in other projects or when the physical interface design changes. By creating re-usable parts at the board level, we believe this will encourage better re-use than more challenging component based recycling solutions [21, 28].

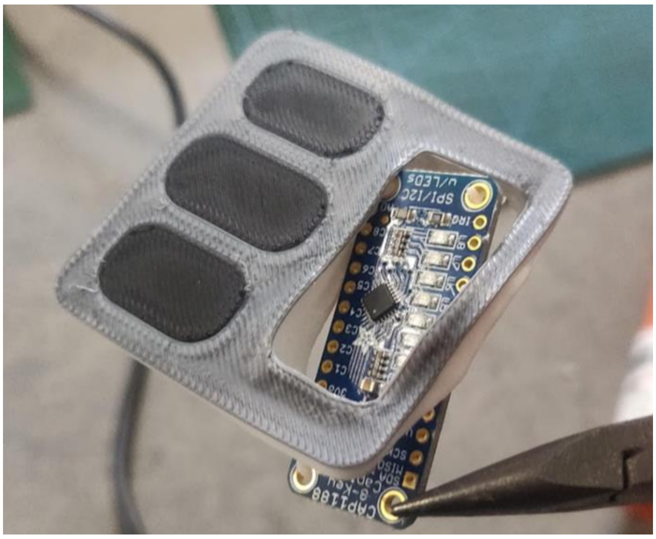

Fig. 4. A board being removed from a print and place prototype after being softened with a heat gun.

## VII. Future work

The development of this process is still in early stages. We would like to keep the requirements of the process in-line what is possible with fabrication devices one could expect a prosumer or hobbyist to own. We envisage that in the next few years multi-tool printing, and more interesting materials will become available, opening up avenues to explore automated part insertion and connections between active components. Already general purpose tool-changing 3D printer platforms are being actively explored in the field of personal fabrication [26] and starting to appear commercially [36]

We also would like to explore the possibilities of adding inspection capabilities into the 3D printers we have, to allow for flying-probe tests and optical inspection of part placement and connections.

## VIII. Author Bio

Oliver Child is a second year PhD student exploring printed electronics for personal fabrication. He likes making things alongside machines. He is inspired by hacker and maker cultures, and interested in understanding why and how groups and individuals make things, and how we can enable more people to make things, whether they be useful devices that may be manufactured at scale, or just projects just for the sake of exploration.

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