CNC Assemblage: Integrating Existing, Physical Objects into New, Digital Designs

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Abstract
Design tools for digital fabrication have opened a wide array of opportunities for creating *new objects* with functional and aesthetic properties. However, CNC tools may also be used to augment and modify *existing objects* for similar purposes. We have begun exploring this second area, with the goal of assisting artists and designers with *assemblage* — integrating pre-existing objects into digital creations. We describe two projects in this space: Makers' Marks, a tool for 3D printing new functional objects from physically annotated sculptures; and Banksybot, a tool for adding surface textures and decorations to existing objects with arbitrary geometry (though our current prototype requires axial symmetry). Our projects both leverage a similar pipeline: first, a user 3D-scans a pre-existing object. Our digital design tools then allow the artist to express augmentations, modifications, or methods of integrating other existing objects. Finally, we use digital fabrication to produce an assemblage through creating a new object or modifying the existing one based on digital designs.

Author Keywords
digital fabrication, design tools, found objects.

ACM Classification Keywords
H.5.2 [User Interfaces]: Fabrication

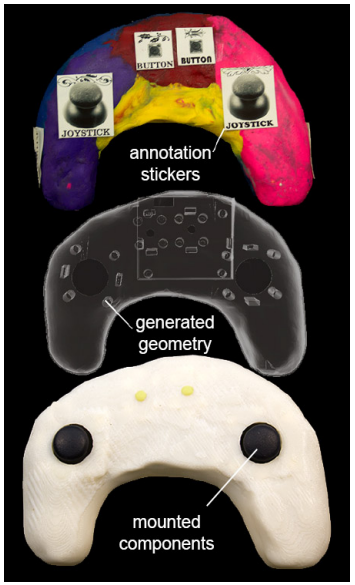

Figure 1: Makers' Marks allows users to sculpt an object and add annotations (top), which it then detects and replaces with appropriate geometry (middle) for a final print (bottom).

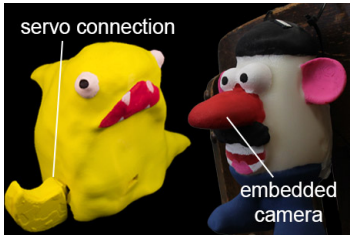

Figure 2: We created several example objects with Makers' Marks, including a sculpted waving shark and a baby monitor based on a potato toy.

Introduction

Significant work has focused on the promise of digital fabrication for designing new objects, whether by sketching in the air [8], "discovering" a 3D model while carving a block [10], or drawing with a laser pointer on a workpiece [4]. However, these techniques constrain artists to specific crafting methods, and do not take full advantage of their existing skill sets, like traditional sculpting or assemblage. We are intrigued by the intersection of intrinsic craft and digital augmentation: as 3D scanners come down in price and increase in quality—following the path of 3D printers, laser cutters, and desktop CNC mills—there are numerous opportunities to capture existing physical objects and include them in digital designs.

Our first project, Makers' Marks [6], focuses on physical objects as *tangible blueprints* for designs that will eventually be fabricated digitally (Figure 1). A user sculpts and annotates a physical shape, then 3D scans it. Our software detects the annotations and adds mounting geometry for parts like buttons or hinges. The designer then prints the augmented object and affixes their functional components.

Our second project, the in-progress Banksybot, uses physical objects as the *canvas* for digital augmentation. Most fabrication techniques assume that their input is homogeneous "material," but this project explores using digital tools to augment existing objects with intrinsic functional or aesthetic value. With Banksybot, an artist 3D scans an object and uses a digital painting program to define surface details to add. Our tool automatically calculates a tool path to preserve user-defined strokes. Then, the artist inserts the object into our modified 3D printer for decoration (Figure 3).

Related Work

Our work draws its inspiration from art that incorporates found objects, and manual processes that partially machine objects of inherent value, for example "live edge" or "slab" furniture[1].

Prior work has explored integration of physical objects into fabricatable designs. CopyCAD [2] and Constructable [4] allow for 2D tracing of existing objects to become a part of a design. Similarly, KidCAD [3] affords stamping existing toys for digital 2.5D remixing. These tools share our goals, but target different types of objects. Bidirectional fabrication [7] also plays into a similar space as Makers' Marks.

3D prints have been explored as a tool for *assembling* [5] or *rebuilding* [9] existing objects 3D printed *enhancements* to existing objects were previously explored by Chen, et al., in Encore [1]. Their tool allows for printing additions on the surface of existing objects. This is similar in spirit to the Banksybot project: giving new life to objects with existing desirable qualities. But rather than single-point 3D printed augmentations, our new project focuses on surface decorations. Banksybot generalizes from the EggBot, which allows for such decoration of ellipsoid objects.

Makers' Marks: Tangible Blueprints for Digitally-Enhanced Functional Objects

Tangible computing devices and smart products embed electronic parts into physical objects. However, integrating electronics and other functional parts into 3D models can be challenging. Mounting components in the right place may require adding fasteners and clearances, or splitting an enclosure into two half shells.

We conducted a formative study that suggested that novices

[1] https://en.wikipedia.org/wiki/Live_edge

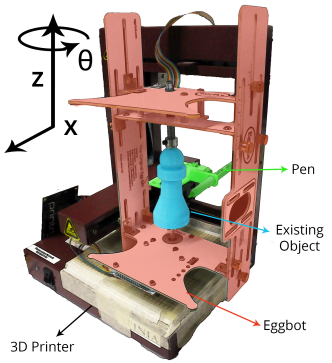

Figure 3: Our machine has two linear axes from a 3D printer and a rotational axis from an EggBot, allowing for arbitrary addressing on existing object surfaces.

Figure 4: We used Banksybot to create two example objects: a chess piece with a barcode and a custom Russian nesting doll.

can express design intent for physical interfaces through a combination of physical sculpting of larger shapes and annotation of finer details, using additional drawings or marks. This inspired us to explore tangible modeling alternatives for CAD.

Makers' Marks, which is fully described in our UIST 2015 publication [6], explores combining the benefits of tangible modeling with the flexibility and precision of CAD: we use physical objects as *tangible blueprints* for final, digitally-fabricated ones. Users sculpt the overall shape they would like to print using clay or other physical materials. They then add physical stickers, indicating placement for functional components (see Figure 1). Our prototype supports electronic (e.g., joysticks) as well as mechanical (e.g., hinges) parts.

We created several objects to showcase the tool's possibilities, like a waving shark based on a clay design, a baby monitor made from a potato shaped toy, and a game controller fit to our hands (see Figure 2).

Banksybot: Using Existing Objects as a Canvas for Digital Augmentation

Surface decorations, like paint or engraving, are used for a variety of artistic and functional object customizations. For example, expiry dates are printed on eggs, and Russian nesting dolls are decorated to have unique faces and bodies. Existing digital fabrication processes only permit surface textures on *new* objects (e.g., through 3D printing) or decoration of existing *planar or ellipsoid* objects (e.g., with a laser cutter or EggBot).

Banksybot is the first step of a larger project to create custom designs on arbitrary existing geometry, employing existing objects as canvases for digital augmentation. The current system can create surface decorations on axially symmetric objects, like chess pawns. This prototype allows users to digitally draw on the surface of pre-captured STLs, using a three.js[2]-based browser painting tool, and represents the user-defined points as a graph. Banksybot then creates machine instructions, which prioritize preserving artist-defined strokes and rapid decoration, through an implementation of the Traveling Salesman Problem. The instructions are sent to our modified 3D printer (see Figure 3). Finally, a user inserts their object into the machine for decoration.

For example, let's say an artist hopes to produce a unique Russian nesting doll for a client. While these are traditionally hand-painted, our artist would like to include a photograph of the client as the doll's face. The artist has a collection of partially hand-painted wooden nesting dolls; they 3D scan one and open the resulting STL in our browser-based interface. The artist drags the desired photo onto an unpainted surface location, and inserts the doll into the machine. After the photo is mechanically printed on the doll's surface, the artist can add more details through traditional hand-painting.

We have produced two example objects thus far with our prototype: a barcoded chess piece and a fabulous-faced Russian nesting doll (see Figure 4). These open several opportunities for continued progress on our project. We would like to find some way of mixing human and machine design work, allowing artists to create new designs from scratch or integrate designs previously made on a computer. Additionally, we are interested in supporting a larger variety of canvas shapes, and have plans to generate 3D printed mounts to hold such objects in place for painting. Finally, we want to probe new types of authoring tools for such designs. We plan to compare tools that use solely digital design (like our current browser-based solution), that have the artist design directly on the workpiece (similar to Makers'

[2] http://threejs.org

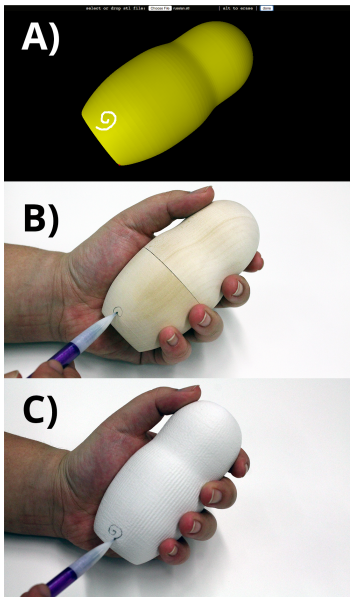

Figure 5: Three types of authoring tools we plan to compare are (a) fully-digital authoring, (b) drawing directly on the workpiece, and (c) using a physical proxy.

Marks), and that use a physical proxy copy of the object (to avoid damage during the design process to an object with intrinsic value) (see Figure 5).

Discussion and Conclusion

The physical → digital → physical pipeline enabled by the increasing availability of 3D scanners is ripe for research, as we have begun to explore in our recent and ongoing projects. We sense that there are opportunities to collaborate with artists, who already have experience working with sculpting or painting materials and found objects.

Our larger research goal is to enable using existing objects as a starting point for new designs. This may mean using a physical object as a template or as a literal part of a final composition—expanding the materials available for digital fabrication to include not just featureless stock material like filament or wooden "blanks," but objects with intrinsic functional or aesthetic value.

We are excited by the possibilities of our tools, and eager to discuss them with others at the workshop. We want to consider specific applications of our work, especially the Banksybot project, as it is still in active development.

References

[1] Xiang 'Anthony' Chen, Stelian Coros, Jennifer Mankoff, and Scott E. Hudson. Encore: 3D Printed Augmentation of Everyday Objects with Printed-Over, Affixed and Interlocked Attachments. In *UIST '15*. ACM, New York, NY, USA, 73–82. DOI: http://dx.doi.org/10.1145/2807442.2807498

[2] Sean Follmer, David Carr, Emily Lovell, and Hiroshi Ishii. CopyCAD: Remixing Physical Objects with Copy and Paste from the Real World. In *UIST '10*. ACM, New York, NY, USA, 381–382. DOI: http://dx.doi.org/10.1145/1866218.1866230

[3] Sean Follmer and Hiroshi Ishii. KidCAD: Digitally Remixing Toys Through Tangible Tools. In *CHI '12*. ACM, New York, NY, USA, 2401–2410. DOI: http://dx.doi.org/10.1145/2207676.2208403

[4] Stefanie Mueller, Pedro Lopes, and Patrick Baudisch. Interactive Construction: Interactive Fabrication of Functional Mechanical Devices. In *UIST '12*. ACM, New York, NY, USA, 599–606. DOI: http://dx.doi.org/10.1145/2380116.2380191

[5] Stefanie Mueller, Tobias Mohr, Kerstin Guenther, Johannes Frohnhofen, and Patrick Baudisch. 2014. faBrickation: fast 3D printing of functional objects by integrating construction kit building blocks. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*. ACM, 3827–3834.

[6] Valkyrie Savage, Sean Follmer, Jingyi Li, and Björn Hartmann. Makers' Marks: Physical Markup for Designing and Fabricating Functional Objects. In *UIST '15*. ACM, New York, NY, USA, 103–108. DOI: http://dx.doi.org/10.1145/2807442.2807508

[7] Christian Weichel, John Hardy, Jason Alexander, and Hans Gellersen. ReForm: Integrating Physical and Digital Design Through Bidirectional Fabrication. In *UIST '15*. ACM, 93–102. DOI: http://dx.doi.org/10.1145/2807442.2807451

[8] Karl D.D. Willis, Juncong Lin, Jun Mitani, and Takeo Igarashi. Spatial Sketch: Bridging Between Movement & Fabrication. In *TEI '10*. ACM, New York, NY, USA, 5–12. DOI: http://dx.doi.org/10.1145/1709886.1709890

[9] Amit Zoran and Leah Buechley. 2013. Hybrid reassemblage: an exploration of craft, digital fabrication and artifact uniqueness. *Leonardo* 46, 1 (2013), 4–10.

[10] Amit Zoran and Joseph A. Paradiso. FreeD: A Freehand Digital Sculpting Tool. In *CHI '13*. ACM, New York, NY, USA, 2613–2616. DOI: http://dx.doi.org/10.1145/2470654.2481361