Fabrication + Interactivity

CMSC730 | Huaishu Peng | UMD CS
Industrial 3D Printer
The new era of personal fabrication
(1) Everyone can design and customize everyday objects.
Long-term vision
(1) Everyone can design and customize everyday objects.
(2) A personal fabricator will construct both its appearance and functionality.

The Economist (Cover)
# Design 3D digital models is difficult

Two challenges for personal fabrication
Two challenges for Personal Fabrication

# Printed objects lack functionality
Fabrication
Fabrication + Interactivity
Fabrication + Interactivity

Interactive Fabrication

Lower the design barriers for 3D modeling

Fabrication for Interaction

Raise the output capabilities of a fabricated object
Fabrication + Interactivity

Interactive Fabrication
Lower the design barriers for 3D modeling

Fabrication for Interaction
Raise the output capabilities of a fabricated object
What are the drawbacks of CAD design tools?

- Implicit design commands
- Complex interface
- No fast physical feedback (intimacy between the designer and the raw material)
Input: 3D digital model

Output: 3D clay model
Olivia White
Olivia White
Olivia White
olivia white
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olivia white
Abstract

We propose a method that allows an unskilled user to create an accurate physical replica of a digital 3D model. We use a projector-camera pair to 3D scan a subject and project multiple frames of a pattern onto the subject. A high-resolution image, which encodes per-pixel depth information, is then acquired using a close-range, high-resolution camera. The user manipulates the patterned region to guide the projection onto the subject. We generate a 3D model of the subject by stitching the 3D scans at the projection boundaries. We then translate the 3D model to a physical replica by carving it from an acrylic resin blank.

1 Introduction

Most people find it challenging to sculpt, carve, or manually form any object. The average person is able to perform any precise manipulation, not because they have superior coordination, but because their movements are usually slow and controlled. Even the most skilled artists can only form objects in a limited range of complexity. A simple 3D model allows users to easily and accurately mimic complex shapes, and accurately reproduce a large range of materials and subtle details.

Keywords: digital fabrication, spatially augmented reality, sculpting

Figure 6: Scanning process: (a) 3D scan of target object. (b) Projection of pattern onto scanned object. (c) Sculpted replica of scanned object.
Structured light 3D scanning

Compare the scanning result with the 3D digital model

Differences are projected at each step with green/red colors
Limitations of this light guidance idea?

Turn-taking (scan at each of the ‘step’)  
Would be hard to do with other material such as wood/foam (because there is no additive process for such material)

Possible solutions?
ABSTRACT
In this paper, we present an approach to combining digital fabrication and craft, emphasizing the user experience. While many researchers strive to enable makers to design and produce 3D objects, our research seeks to present a new fabrication approach to make unique, one-of-a-kind artifacts. To that end, we developed the FreeD, a hand-held digital milling device. The system is guided and monitored by a computer while preserving the maker’s freedom to sculpt and carve, and to manipulate the work in a many creative ways. Relying on a pre-defined 3D model, the computer gives the user control only when the milling bit makes the desired cuts. The system is capable of cutting a new model by simply moving the tool along a surface. We describe the key components of our work and its integration, present the FreeD’s architecture and technology, and discuss two projects made with the tool.

Author Keywords
Computer-Aided Design (CAD), Craft, Digital Fabrication, Carving, Milling.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces.

INTRODUCTION
Over the last several years, digital fabrication technologies have afforded new disciplines [4]. Today’s designers can easily create, develop, or modify a Computer-Aided Design (CAD) model of their desired object, and fabricate it almost instantly using a digital process. In developing new manufacturing technologies, engineers seek an optimal solution, reducing the process to as few parameters as possible, and separating design from fabrication. Ease of use, accessibility, predictability and efficiency grow in technology matrices. However, qualities such as creative engagement in the experience itself are lost. The nature of interaction with the fabricated artifacts is rarely the focus of new developments. While the process of engineering innovation rules, speed, efficiency, and enables automation and repetition, craft is above involvement and engagement, uniqueness of the final product, and authenticity of the experience [7]. Engaging in an intuitive fabrication process and enjoying the experience of shaping raw material are inherent values of traditional craft. As a result of this engagement, handmade products are unique and carry personal meaning [19].

Our research interest lies in the cross-section between Digital Fabrication and the study of the craft experience. We wish to allow designers to engage with the physical material not only the CAD scripts and tools. We hope to encourage the exploration of an intuitive digital fabrication approach, introducing craft qualities into the digital domain. Our contribution is a system mapping qualities of both traditions: removing fabrication risk by using a small degree of digital control and automation while allowing authentic engagement with raw material to achieve unique results.

The FreeD is a handheld digitally controlled milling device (Figure 1). With the FreeD we harness CAD sketches in 3D design while keeping the user involved in the milling process. A computer maintains this 3D interaction while preserving the maker’s freedom to shape the work. The computer intervenes only when the milling bit approaches the 3D model. In such a case it will either slow down the spindle, or slow back the shaft, the rest of the time it allows the user to freely shape the work. Our hope is to substantiate the importance of engaging in a discourse that provokes a new hybrid entity: for fabrication and discovery – a territory of artifacts produced by both machines and man.

Figure 1: (A) The FreeD and (B-C) the process of making a bowl from polyethylene foam.
Tracking: 6DOF Magnetic tracking
Control: stop milling at the edge of the digital model
Control can be overridden with manual control

What can this do that the previous project cannot?
user can manually switch between different reference virtual models during the work
What if we have no digital model at the beginning? What if we hope to design a 3D model from scratch?
D-Coil: A Hands-on Approach to Digital 3D Models Design

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ABSTRACT

We introduced D-Coil, a new digital 3D modeling approach using wax coiling to bring tangibility to the design of digital models. After defining a shape to create, the user places the thread into a mold and applies pressure to make the thread into a coil. The user then places the mold into a 3D printer to make the digital model. The 3D-printed object is then used to create the final object. This process is repeated until the final object is complete. The final object is then used to make a digital model. The digital model is then used to create a final object.

Author Keywords

Computer-aided Design (CAD); Craft; Digital Fabrication; Experiments.

ACM Classification Keywords

H.5.2 [Information interfaces and presentation]: User interfaces.

INTRODUCTION

As predicted by Gershonfeld [13], we have seen a rapid advancement towards the democratization of 3D printing in recent years. One can now design and print with the ease of desktop printing in the 1980s [13], with one significant difference: it is still difficult to create complex digital models ready for 3D printing. Though the interface of CAD systems has been vastly improved, the learning curve remains steep and creating complicated, smooth shapes requires the mastery of complex construction commands (such as lofting between multiple contours using guide curves). Further, the intuition of the design and fabrication process in digital CAD software makes it difficult for all.

Figure 1. (a) Wax Coiling parts of a D-Coil object. (b) Wax Coiling parts of a D-Coil object. (c) Wax Coiling parts of a D-Coil object.

but experts to anticipate how a digital model will look and feel once it is built. This stands in sharp contrast with traditional craft activities such as clay coiling in which design and construction can occur at the same time. As observed by Schein [13], the interactivity between the designer and the material at hand enables a constant reductive consideration promoting a sense of immediate feedback. Using a digital object to make a digital model and printing the final model allows for a seamless process to create highly complex models (high fidelity) [18].

CHI 15
Peng et al.
3D modeling with no CAD interface

No CAD Interface
No implicit building commands
Constant tangible feedback
D-Coil

No CAD interface
Digitalization

Slow in building speed
Not for CAD users
What if we can have a system for CAD users but with timely physical feedback?
On-The-Fly Print: Incremental Printing While Modeling

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ABSTRACT
Current interactive fabrication tools offer tangible feedback by allowing users to work directly on the physical model, but they are slow because users need to participate in the physical instantiation of their designs. In contrast, CAD software offers powerful tools for 3D modeling but delays access to the physical world until the end of the design process.

In this paper we propose On-The-Fly Print, a 3D modeling approach that allows the user to design 3D models digitally while having a low-fidelity physical prototype printed in parallel. Our software allows printing features as soon as they are created and updates the physical model in real-time. Users can quickly check the design in a real-use context by removing the printed physical print from the printer and replacing it afterwards to continue printing. Digital content modification can be updated with quick physical correction using a tactile feedback cutting blade. We present the detailed description of On-The-Fly Print and showcase several examples designed and printed with our system.

Author Keywords
3D printing, fabrication, computational craft, CAD, rapid prototyping, interactive objects.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

INTRODUCTION
Since the notion of interactive fabrication was introduced by Will et al. [12], several approaches have been proposed for hands-on digital fabrication. For example, Constructible [17] allows the step-by-step fabrication of functional objects using a laser cutter controlled by a laser pointer. X-Cell [18] allows non-experts to design 3D digital models from scratch using a digitized control point editor. Refills [31] merges mental modeling with digital modeling and extrusion of synthetic sky. On the one hand, these interactive fabrication systems offer immediate, tangible feedback that can benefit

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CHI 16
Peng et.al.
3D modeling while 3D printing
3D modeling while 3D printing

- Design + print from scratch < 10 min
- The user can focus on digital design
- The user can check physical prints early on
To support design and fab in parallel, our machine should be able to:

- print fast
- print incrementally
- make subtractive changes
To support design and fab in parallel, our machine should be able to:

- print fast *(to catch up the CAD design speed)*
- print incrementally
- make subtractive changes
A pair of mist cooling nozzles
Extended extruder tip
To support design and fab in parallel our machine should be able to

- print fast
- print incrementally (to avoid reprint every time)
- make subtractive changes
Rotational rail (B axis)

Rotational rod (C axis)
To support design and fab *in parallel*
our machine should be able to

print fast
print incrementally
*make subtractive changes* (to reflect digital editing)
To allow the designer to focus on the design, our software should be able to:

- print new primitives automatically
- solve potential collisions
Software Workflow

- design new primitives in CAD
- slice: solid model to sliced model
- optimize printing order
  - Relaxing printing orientation
  - Out of order printing
  - Omitting geometries
- optimize printing angle
- print physical preview
- print physical preview to g-code file
- current print is done
In-situ Design and Fabrication
RoMA: Interactive Fabrication with Augmented Reality and a Robotic 3D Printer

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ABSTRACT
We present the Robotic Modeling Assistant (RoMA), an interactive fabrication system providing a fast, precise, hand-assisted and 3D modeling experience. In a designer-robotic collaboration scenario, a designer creates a digital abstract model of a physical prototype in an immersive environment, which is concurrently fabricated by a 3D printing robotic arm. The hand-assisted robotic fabrication process is controlled by a controller that can be held in the hand or on a table. A tangible model serves as a tangible reference for the designer as she adds new elements to her design. RoMA’s presence-inspired handshake mechanism between the designer and the 3D printing robot can allow the designer to quickly transfer designs to a printed area or to indicate that the selection task is not yet complete. The novelty of RoMA is the designer and the robot working together in a design loop, allowing them to create with proportional tangible additions or to avoid making mistakes. We conclude by presenting the strengths and limitations of our current design.

Author Keywords
3D modeling, Augmented Reality, Interactive Fabrication, CAD, Rapid Prototyping, Physical Prototyping.

ACM Classifiers Keywords
H.5.2 [Information interfaces and presentation]: User interfaces

INTRODUCTION
Interactive fabrication [10] marks a hardware approach during the 3D modeling process to offer a reflective design experience. This concept has been developed with several approaches [3]. For example, Constructive [26] proposes a step-by-step user control process to design 3D models that have 2D printed objects. De-CAD [28] allows the user to create a 3D digital model by directly handbuilding in a physical counterpart. Our system is an improved version of this approach that involves a physical counterpart. The 3D CAD model is created using traditional CAD software. The physical counterpart is fabricated using our 3D printing robotic arm and the designer quickly improves the design. De-CAD allows the designer to adjust the size of the 3D model based on the physical prototype.

Figure 5. In RoMA, a designer, the designer creates a digital space, while the robot prints the shape back. Digital model is updated after the physical model.
AR headset
AR controller
Rotating platform
Robotic 3D printer
Printing using the wireframe structure
Design and fab happen in parallel
Step into the 3D printer
Using the user’s body as design reference
Using partially printed model to support next design step
Design and fabrication directly
ON a physical object
Proxemics-based interaction

Designer Zone 1

Robot Prints

Robot Parks

Designer Zone 2

Designer Zone 3
Proxemics-based interaction

User touches and rotates

Robot parks automatically
Proxemics-based interaction

User leaves the design scene

Robot takes control of the platform
Design on an object
Adding and removing material is still very slow
Can we *directly reshape* the material?
Formative manufacturing

Subtractive manufacturing

Additive manufacturing
FormFab: Continuous Interactive Fabrication

Mueller et.al.

ABSTRACT

Several systems have illustrated the concept of interactive fabrication, i.e., rather than working through a digital editor, users make edits directly on the physical workspace. However, so far the interaction has been limited to non-scaling, i.e., users first perform a command and then the system responds with physical feedback. In this paper, we present a first step towards interactive fabrication that changes the workspace continuously while the user is manipulating it.

To achieve this, our system FormFab does not add or subtract material but instead operates in “continuous fabrication”. A heat gun attached to a robotic arm warms up a thermoplastic sheet and a force sensitive resistor (FSR) that controls the heat while it pushes the sheet, thereby pushing the material outward or pulling it towards.

Since FormFab unfolds the workspace continuously while users are moving their hands, users see intuitively explore different states of a shape with a single interaction.

Author Keywords: personal fabrication, interactive fabrication, direct manipulation, 3D modeling tools

INTRODUCTION

Recently, Wilks et al. [18] proposed the concept of interactive fabrication. The key idea is to bring the principles of direct manipulation [18] to the editing of physical objects. Instead of working on a digital 3D model and producing the physical result only at the end, users make edits directly on the physical workspace and see it change immediately.

Early interactive fabrication systems, such as Shaper [20], eProdGeist [15], and constructible [14], allow for hands-on editing on the physical workspace. However, their interaction is best described as non-scaling: users first produce their input to the system and then the system responds with physical feedback. Since there are two discrete steps, users can only explore one option per turn [19].

Figure 1: FormFab changes the workspace continuously while the user is interacting with it. (a) A heat gun warms up the workspace. Once the material has become compliant, (b) the user’s hand gestures interactively controls a pneumatic system that applies pressure or vacuum, pushing the material outward or pulling it towards.
Selectively heat the material

Directly manipulating the area with gestures
Limitations
Slow heating process
Limited expressiveness

How to further improve the system?
What if we can generate physical models in seconds?
What if we can generate physical models in seconds?

Fast shape changing speed
But only 2.5D
And it’s not detachable
Fabrication + Interactivity

Interactive Fabrication
- Lower the design barriers for 3D modeling

Fabrication for Interaction
- Raise the output capabilities of a fabricated object
Fabrication + Interactivity

Interactive Fabrication

Lower the design barriers for 3D modeling

Fabrication for Interaction

Raise the output capabilities of a fabricated object
A 3D Printer for Interactive Electromagnetic Devices

Huaishu Peng | François Guimbretière | James McCann | Scott Hudson

UIST 2016
Winding continuous strands of wire inside a 3D printed object across printed layers.

- Isolated copper wire
- Soft iron wire
Printer head design
5DOF printing platform
Generate coiling posts
Generate/vis soft iron core
Generate/vis copper coil
Generate all G-codes accordingly
Example 2: Physical display
a physical progress bar with Ferrofluid

Generalization: tangibles and shape changing display
Example 4: **Printing motors**

- Printing circular base
- Printing a coiling jig
- Printing winding posts
- Coiling soft iron core
- Coiling copper

Repeat x6

Motor stator

Reluctance rotor

Magnet rotor
Example 4: Printing motors

A magnet rotor holder
Example 4: Printing motors

a printed reluctance rotor
Thermorph

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Morphing Matter Lab
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Shape memory of thermoplastic

Shape memory thermoplastic has the capability of changing its shape upon temperature changes.
Shape memory of thermoplastic

During the printing process, the polymer chain is being rearranged and residual stress can be built: when PLA is being extruded, the polymer chain is pulled and straight; it will be forced to keep the straight state after it quickly cools and solidifies.

If we reheat the solidified PLA, it will release the residual stress, shorten along the printing direction.
Shape memory of thermoplastic

a bi-layer structure: one layer of Thermopolyurethane (TPU) as the constrain layer and three layers of PLA as the active layer. Together these four layers form an actuator.
Shape memory of thermoplastic
Long-term vision
(1) Everyone can design and customize everyday objects.
(2) A personal fabricator will construct both its appearance and functionality.
Long-term vision
(1) Everyone can design and customize everyday objects.
(2) A personal fabricator will construct both its appearance and functionality.
Optional readings

RoMa: Interactive Fabrication with Augmented Reality and a Robotic 3D Printer
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ABSTRACT
We present the Robotic Modeling Assistant (RoMa), an inter-active fabrication system providing a fast, precise, hands-on and intuitive modeling experience. As a designer creates a new model using RoMa AR CAD tools, features are instantiated computationally by a 3D printing robotic arm and physically fabricated in real time. The virtual to physical model flow serves as a tangible reference for the designer as she interacts with new features in her design. RoMa’s presentation-support haptic feedback mechanisms between the designer and the 3D printing robotic arm allows the designer to quickly interact, inspect, and re-design the printed model to access a primal sense or to indicate that the robot can take full control of the model to finish printing. RoMa’s AR canvas integrates real-world constraints into a design rapidly, allowing them to assess well-defined tangible artifacts or to create existing objects. We evaluate by prototyping the strengths and weaknesses of the RoMa system.

Author Keywords
3D printing, Augmented Reality, Interactive Fabrication, CAD, Rapid Prototyping, Physical Prototyping.
ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces
INTRODUCTION
Interactive fabrication [14] enables a hands-on approach during the 3D modeling process to offer a 3D design and fabrication process that is not limited to conventional 3D modeling approaches [3]. For example, Construct2D [2] proposes a step-by-step, step-by-step editing system to design 3D assemblies, from 2D physical pieces. 3DCAD [3] allows the user to create a 3D digital model by directly handbuilding it. The design can be fabricated as a printed object.

Our system combines the benefits of the two approaches: a hands-on, hands-on, and direct way of editing a digital model using the designer’s hands, and a 3D printing robotic arm to bring the printed object to life. Our software system provides a user interface enabling a hands-on approach to the design process, while a robotic arm moves the physical digital model from the virtual world to the real world. Our system allows the designer to design a 3D model by hand, and then to interact with the physical model. The 3D model can then be fabricated using a 3D printing robotic arm.

KnitUI: Fabricating Interactive and Sensing Textiles with Machine Knitting
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Author Keywords
Machine knitting, Textile computing, Wearable computing, Interactive textile
ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces
INTRODUCTION
With the advent of wearable electronics and smart interfaces, digital fabrication of interactive and sensing textiles is becoming an increasingly important area of research. Machine knitting is an emerging technology that allows the creation of complex, three-dimensional textile structures using computer-controlled knitting machines. This technology enables the integration of electronics and other functional components directly into the textile structure, providing a unique means of creating interactive and functional textile interfaces.

ABSTRACT
With the advent of wearable electronics and smart interfaces, digital fabrication of interactive and sensing textiles is becoming an increasingly important area of research. Machine knitting is an emerging technology that allows the creation of complex, three-dimensional textile structures using computer-controlled knitting machines. This technology enables the integration of electronics and other functional components directly into the textile structure, providing a unique means of creating interactive and functional textile interfaces. Machine knitting offers several advantages over traditional textile manufacturing methods, including the ability to create complex shapes and structures, as well as the potential for creating interactive and functional textile interfaces. Additionally, machine knitting allows for the customization of textile structures, enabling the creation of unique and personalized products. This technology has the potential to revolutionize the textile industry, offering new possibilities for the creation of wearable technologies and interactive textile interfaces.