Introduction to Personal Fabrication
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Dark Patterns
Textile Interfaces

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What is Personal Fabrication?
How can we empower everyone to create physical objects with ease?
Digital Fabrication
Digital fabrication tools turn bits into atoms, i.e. they create **material objects from digital designs**.

- Catarina Mota, The Rise of Personal Fabrication, C&C’11
Shaping Textile Sliders

Nowak et al., CHI’22
Textile Icons

Schäfer et al., CHI’23
Autodesk Fusion 360
Digital fabrication tools turn bits into atoms, i.e. they create material objects from digital designs.

- Catarina Mota, The Rise of Personal Fabrication, C&C’11
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What is a fab lab?
Fab labs are a global network of local labs, enabling invention by providing access to tools for digital fabrication.

What's in a fab lab?
Fab labs share an evolving inventory of core capabilities to make (almost) anything, allowing people and projects to be shared.

What does the fab lab network provide?
Operational, educational, technical, financial, and logistical assistance beyond what's available within one lab.

Who can use a fab lab?
Fab labs are available as a community resource, offering open access for individuals as well as scheduled access for programs.

What are your responsibilities?
safety: not hurting people or machines
operations: assisting with cleaning, maintaining, and improving the lab
knowledge: contributing to documentation and instruction

Who owns fab lab inventions?
Designs and processes developed in fab labs can be protected and sold however an inventor chooses, but should remain available for individuals to use and learn from.

How can businesses use a fab lab?
Commercial activities can be prototyped and incubated in a fab lab, but they must not conflict with other uses, they should grow beyond rather than within the lab, and they are expected to benefit the inventors, labs, and networks that contribute to their success.

http://fab.cba.mit.edu/about/charter/
Who can use a fab lab?

Fab labs are available as a community resource, offering open access for individuals as well as scheduled access for programs.
How do we connect this to HCI research?
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https://www.creality.shop/products/ender-3-3d-printer – 23th June 2023
Interfaces
Visicut

By Thomas Oster
Processes
If we go back to the beginnings of interactive computing, early computer users were probably reasonably happy placing their punch cards into the reader and waiting for their output to arrive hours later—which is pretty much where 3D printing stands today.

- Patrick Baudisch, Personal Fabrication in HCI: Trends and Challenges, AVI’16
ReForm: Integrating Physical and Digital Design through Bidirectional Fabrication

Christian Weichel
John Hardy
Jason Alexander
Hans Gellersen

From Lancaster University

UIST’15
ReForm

Integrating Physical and Digital Design through Bidirectional Fabrication

video: Robert Potts and Daniel Morrell (Ourus LTD)
Bidirectional Fabrication
More targeted operations require the selection of an area of influence. We use annotation-input to enable users to mark the area they want to manipulate on the physical object.

Due to ReForm's malleable material, users can modify the physical objects directly and in context. As the material is malleable when heated to approximately 50°C, Réne Schäfer explains the benefits of using ReForm for manual fabrication methods with one material.

Hardware

Weseparated the hardware into two main components: the machine with a custom clay extruder and milling spindle; a light 3D scanner; annotation detection and custom toolpath generation to use our machine's capabilities.

Material

Common polymer clays and putties are too soft to be machinable, yet malleable when heated to approximately 50°C. They are difficult to work with physically aligned augmented reality interface; a structured surface (with a normal parallel to the average normal of the flattening patch) is created at the determined height.

Extrusion (Figure 4, a) adds depth to the annotated outline determined based on the mean height of the annotated area. Within the annotated area, a smooth surface (with an approximate of 0.1mm) is created. The cutting height is automatically determined based on the average height of the flattened area.

Through annotations users can also issue commands, selecting the area they want to replicate, and a reference point in the digital domain. To create a pattern (Figure 4, c), users select the area they want to replicate, and a reference point in the digital domain. To create a pattern, the selected area is replicated accordingly.

Replicating patterns is tedious to do manually, but effortless through the graphical user interface. While choosing which version to revert to, ReForm allows us to restore the previous state undoing the manual interaction is required. The cutting height is automatically determined based on the average height of the annotated area.

Extrusion (Figure 4, a) adds depth to the annotated outline determined based on the mean height of the annotated area. Within the annotated area, a smooth surface (with an approximate of 0.1mm) is created. The cutting height is automatically determined based on the average height of the flattened area.

Local flattens serve the same purpose as its global counterpart: remove undesirable physical manipulation artifacts. Below, it makes for an intuitive design process.
DISCUSSION

Through our implementation and design walkthroughs we learn several practical lessons from realising bidirectional fabrication. Our current implementation solves model-object registration by fixing the object to a build-plate, thus enforcing a fixed reference frame. While this approach simplifies implementation, it also limits what users can do with the physical object — e.g. the side attached to the build-plate cannot be modified. To do away with the build plate, one could use the Iterative Closest Point algorithm \[27\] or apply infrared registration markers e.g. spraying a random dot pattern. However, being able to externally machine an object requires it to be held firmly in position. The accuracy/fabrication time trade-off can be tuned at runtime of the system, making it more flexible. If high accuracy is required, the more precise of the two fabrication methods can be used and the machine can move slower. If short fabrication times are desired, a more coarse fabrication method is used at higher speeds. For example, in our prototypes subtractive operations are more precise than additive ones. Thus if accuracy is required, we can refine additively fabricated features subtractively.

Technical Limitations

Due to tolerances of the fabrication process, we can take an object after each physical update and update the digital model accordingly. This can lead to an accumulative error, thus making the model degrade over time. A relaxed object/model correspondence, where only desired changes are integrated into the digital model would remedy this problem.

Optical 3D scanners require all parts of the 3D model to be visible to them. Thus, concavities and hollow areas are difficult to capture. By integrating multiple 3D scanners, we could capture the physical object to a greater extent. Similarly, the digital fabrication stage is limited by what it can physically reach. Using all five axes for fabrication would increase the set of fabricable shapes, but also increase the algorithmic toolpath generation complexity.

Alternative Implementations

Other forms of implementing ReForm and bidirectional fabrication are possible. If only one fabrication method were automated, the other method could be performed manually e.g. computer-controlled milling and manual material additions similar to Sculpting by Numbers \[16\]. Bidirectional fabrication could also be implemented by combining automated construction kit assembly (e.g. LEGO\textsuperscript{R}) utilizing automated brick layout algorithms \[21\], and some shape-sensing capabilities integrated into the construction kit.

Multi-material printers could be used to implement a bidirectional fabrication process offering a whole new range of interactions. Malleable and hard materials in the same object could be used to express constraints. Built-in curvaturesensors using printed optics \[25\] would make the artifact itself interactive, or even enable them to sense their own shape.

CONCLUSION

In this paper we introduced bidirectional fabrication; a concept whereby digital and physical objects are entangled so that updates to one always propagate to the other. This enables users to design objects using precise repeatable digital operations, intuitive expressive physical actions, and combinations of both. To evaluate this concept, we built ReForm: a scan
print.
Bidirectional fabrication fundamentally changes the digital fabrication design process and produces a range of advantages. The process, through iterative addition and/or subtraction of material, allows objects to iteratively evolve. The creation process is currently unidirectional: the user generates or customises a digital model of the object, which is then sliced and sent to a machine to fabricate the physical object. The machine then updates the digital representation. Consequently, users are tied to digital models. Once an object is fabricated, it is separated from its originating digital model. This results in a one-way design pipeline, while the machine can only influence the physical object during fabrication. This produces a rigid separation between work-spaces: the user over to a machine, to fabricate the physical object. This setup does not support subsequent redesign.

To overcome the rigidity of the conventional fabrication process, we introduce ReForm: a system that integrates digital modeling with shape cutting. ReForm fundamentally changes digital fabrication by allowing users to move flexibly between working on the digital and physical models. Through both digital and physical input, we introduce an iterative fabrication process that allows objects to iteratively evolve. To demonstrate the benefits of ReForm to the digital creation process, we build a system that integrates digital modeling with shape cutting and physical input to produce physical objects based on digital models. The virtual design must be completed before fabrication, and once fabricated, re-shaping the physical object is not possible. Consequently, users are tied to digital models. Once an object is fabricated, it is separated from its originating digital model. This results in a one-way design pipeline, while the machine can only influence the physical object during fabrication. This produces a rigid separation between work-spaces: the user over to a machine, to fabricate the physical object. This setup does not support subsequent redesign.

Through application experiments, we demonstrate the benefits of ReForm to the digital creation process. We leverage the physical strengths of shape cutters, allowing users to produce objects with a range of geometric details. We also shape and annotate the physical object directly. Second, it enables tasks requiring precise input or representation to be better done using digital tools. Third, the physical object is not rigid and fabricated in a single pass, but can evolve in the production process. The virtual model supports object versioning to allow users to alter the object and digital representation. Consequently, users are tied to digital models. Once an object is fabricated, it is separated from its originating digital model. This results in a one-way design pipeline, while the machine can only influence the physical object during fabrication. This produces a rigid separation between work-spaces: the user over to a machine, to fabricate the physical object. This setup does not support subsequent redesign.

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Toolkits
Kyub: A 3D Editor for Modeling Sturdy Laser-Cut Objects

Patrick Baudisch
Arthur Silber
Yannis Kommana
Milan Gruner
Ludwig Wall
Kevin Reuss
Lukas Heilman
Robert Kovacs
Daniel Rechlitz
Thijs Roumen

From Hasso Plattner Institute

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The Reflective Maker: Using Reflection to Support Skill-learning in Makerspaces

Dishita Turakhia
Peiling Jiang
Brent Liu
Mackenzie Leake
Stefanie Mueller

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Digital Fabrication

Manufacturing

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Novice Users

Research