Learning Underlying Principles of Physicalization by Tangible, Embodied, and Iterative Fabrication

Jeeeun Kim
Computer Science
University of Colorado Boulder
jeeeun.kim@colorado.edu

Abigale Stangl
ATLAS Institute
University of Colorado Boulder
Abigale.stangl@colorado.edu

Tom Yeh
Computer Science
University of Colorado Boulder
tom.yeh@colorado.edu

Abstract

Recent advances in digital fabrication (DF) technology enabled designers to easily physicalize conceptual ideas, virtual designs, and information data into tactual forms. Albeit designers' natural tendencies to iteratively refine ideas and apply their discoveries from the physicalization process into the next iteration, today's DF machines do not support live design in-situ, tight feedback loop, or an opportunity to intervene making process by physical design actions-- that a designer can intuitively learn underlying principles of fabrication with their muscle memories. In this paper, we propose *Human Fabrication Interaction (HFI)*, novel interaction techniques that provide a natural mapping between embodied design activities and physical objects being produced. A designer will not only interact with the virtual model or design tools, but s/he should be also able to interact with the fabricator's behaviors and partial outcomes generated by physical mechanisms.

Author Keywords

HFI; Physicalization; Physicality of Fabrication Process;

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

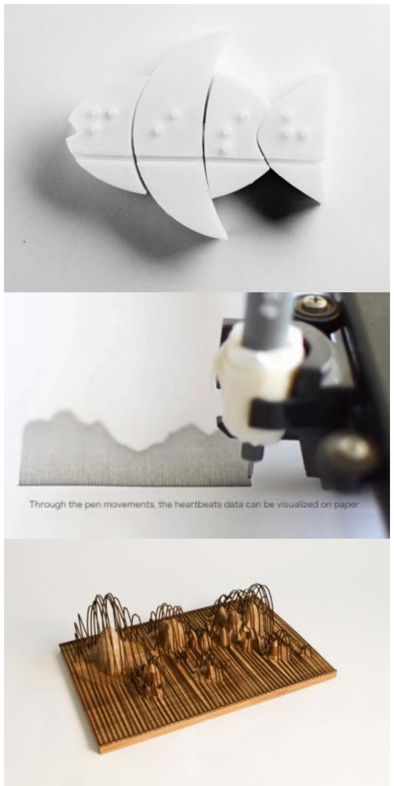

Figure 1. Fabrication became a promising method to produce tactile materials to develop literacy (top, by 3D printing) [1], to physicalize conceptual idea such as bio data(middle, by a mechanical plotter) [7], and generate tangible representation of scientific notion such as world GDP (bottom, by lasercutting) [2], and so forth.

Fabrication as A Physicalization Method

Thanks to recent advances in personal fabrication technology and the wealth of online sharing communities of digital models along with instructions, such as Thingiverse[1] and Instructables[2], the makers 's community can easily become creators using digital fabrication (DF) techniques. They can make their ideas become physical objects, which we refer to as data physicalization, and earned easy access to the DF as an object physicalization method, gradually creating innovate their ions on craft practices.

DF has become one of the promising approaches to replace manual routines of handcraft that physicalize information, conceptual ideas, scientific notion, and more (See Figure 1) in precise, meticulous form that human hands might not able to achieve. Empowered by a rich set of predefined templates and primitives for a reinterpretation of contents [6], designers with different level of skillsets are able to create digital models that will be produced in a palpable form via fabricators. Further, burgeoning of free software that supports parametric design, for example, CraftML, enabled easy customization and modifications to adapt unique individual needs [4].

Lost Muscle Memories of Physical Designing

Unfortunately, even if designers with different background and skillset can easily design physical materials in a digital platform, the hands on, embodied and tangible experiences of design are often reduced. Like in traditional craft practices, the embodied and tangible experience of designing physical objects provides one with a deeper, material understanding of what they are creating and an intuitive appreciation about underlying mechanisms of procedures in physicalization activities—that are missing in current fabrication pipeline with DF tools.

Current fabrication process by DF machines disconnects a designer's muscle memory of the creation process, which is traditionally learned through physical experiences that have been natively supported in conventional handcraft practices. The simple action of 'drawing a circle' provides young children kinematic motor memory to move her arm around the shape to complete the task. Similarly, folding origami, quilling, *etc.,* assign makers the memory of force added to the material or hand tools to handle them, direction to add force, and tactile experiences on hands.

Looking back on our memories of conventional craft practices (*i.e.* knitting, ceramic throwing, and glass blowing), designer's engagements in a tight feedback loop to recall such muscle memories, from materiality to a process managing them, let the designer decide physical form factors to produce a final outcome in-situ. For example, in a ceramic throwing process, a designer kneads clay, by feeling the viscosity and elasticity while s/he prepares the material, and so slightly differentiate hand force to handle clay, hand tools to mold/carve/ sculpt, and the amount of supplementary materials being added to the creation process [3].

Tight Feedback Loop to Make in-situ Design Decision

[1] http://www.thingiverse.com
[2] http://www.instructables.com

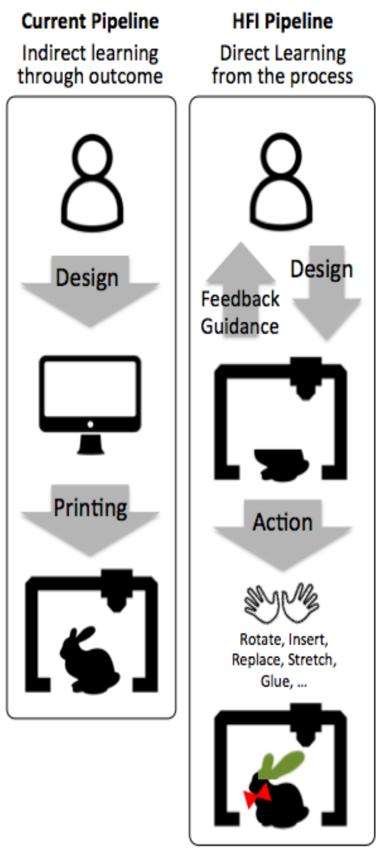

Figure 2. With the HFI, users can learn the physicality of physicalization process, touching not only the produced outcome, but also the physicalized procedures in the entire fabrication pipeline.

As designers, makers, and creators become familiar with operating DF tools, such as 3D printers and laser engravers, they may start to notice how the fine tuned machines perform specific actions and parameters and the impact these actions have on different materials, and vice versa. For example, a cherry plywood get different engraving effects from the same settings applied to oak plywood. Designers also obtain contrasting result by applying different machine settings, for example, various laser frequencies and a nozzle's movement speeds to laser, to the same materials. A tight feedback loop allows designers to see effect right away, to adapt live consequences and update design decision along with. Such benefit is never acquired in a virtual designing process, only via physical designing activities.

Physicality in Physicalization Process

Currently, users' design activities are mostly conducted at screen based CAD tools, restraining the information flow in a uni-directional pipeline as illustrated in Figure2 left. It limits the ability of physical, live, and direct manipulations of the product being produced in the middle of process. As mentioned above, many designers only get a glimpse of the material/machine relationship at the final stage of production. Although the latest innovations in designing applications effectively provide fluid and flexible rendering result projected on screens, a chasm between a digital model created by a designer from CAD tools and a physical form produced by fabricators is not tightly interpolated. Unlike traditional craft practices where designers participate in the entire creation process to reinterpret the initial idea, change and update design idea in-situ, in a current DF pipeline, designers certainly lose their control on various aspects that affect details of the final outcome.

In contrast, a proactive approach to participation in this process will enable designers to make iterative interventions in their designs, and to quickly experiment with design actions that produce real-time, physical partial outcomes, that needs to be gradually adapted into the final object. (See Figure2 right). This approach allows the designer to see the live aftermath of their design actions so that they can understand how fabricators' behavior affects the physicalized objects and adapt such effects into their design in-the-wild.

Interaction with a partial outcome

Once a designer starts to interact with not only CAD design tools or a virtual design of model, but also with the fabrication process itself, and partial outcomes they are actively producing within it—they will be able to get muscle memories of physicalization activities, learning the process with bodily remembrance. Designers' direct interaction with the process and partial outcomes will allow open communication between a user and DF tools. They will be allowed to make live ad-hoc design decisions, so can touch the production 'process' of physicalization, as well as physical artifacts produced.

Learning Underlying Mechanisms of Physicalization

We propose HFI, human-fabricator interaction, which changes the perspective to see fabrication as a live physicalization method. HFI frees users physicalization activity from CAD-based interaction, leading towards a tangible, accessible real-time intervention during the production process [5]. It also enables designers to mingle digital design and existing real-world objects, enabling direct modifications of an object that is being physicalized, by understanding unique properties of materials, and adapting physical dynamics occurred in a creation process. Throughout a live, tangible, and embodied interaction between a designer and fabricators, HFI will teach users various basics of principles to construct physical object-- *i.e.* constructive geometry operations to create a new shape, binary operations between existing 3D shapes, and physical settings that control the behaviors of machines.

In that vein, such activities let users gradually comprehend the underlying mechanisms of design activities, for example, appreciate 'subtraction' or 'intersection' by inserting a real-world material into an object being produced from an original digital model set to machine's production cycle. Furthermore, understanding machine specific parameters by seeing the direct mapping between designers' design actions and generated partial results in a tight feedback loop, will benefit designers by supporting opportunity of re-thinking design, making decisions in-situ, applying adjusted techniques to deliver right context of physicalized contents.

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