Co-Designer Robot: Human-Fabrication Machine Interaction (HFI)

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Abstract

Instead of acting as intelligent agents to support designers' natural tendencies to iteratively refine ideas and discover new techniques, today's fabrication machines operate in order-execute command mode. In this paper, we argue that the machine should socially interact with a human in real-time, perceive their gestures to understand the emerging design process, ask for instruction, inform, and guide the best options reflecting human action. We define the *Human-Fabrication Machine Interaction (HFI)*, to consider the importance of (i) interleaved design thinking during fabrication, (ii) socially enriched interaction with machines, and (iii) concurrent human and machine interaction by switching task leadership, maximizing the benefits of each.

Author Keywords

Human-fabrication machine interaction; concurrent collaboration; creativity support; emerging design

ACM Classification Keywords

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

Introduction

Recent advances in computational fabrication tools, defined here as one exemplar form of robots with limited DOF but possessing a sufficient level of precision, have enabled a wide array of users' access to a multitude of techniques that support their creative endeavors. However, unlike a real world creative process that involves co-design with living cohorts at art studios, maker spaces, or in-the-wild design sites, social interaction through the entire fabrication walkthrough has never been realized. Design decisions happen not only during ideation and design time, but continually throughout the entire lifetime of a creative work [8]. Creativity thus comes from a successful meeting of ideation, prototyping, hands-on activities, refinement, and iteration of all these processes, which is different each time. Limited interactions — those without the exchange of opinions about predicted outcomes, meta-perceiving on-the-fly reflection, and gaining feedback and task compromise (example shown

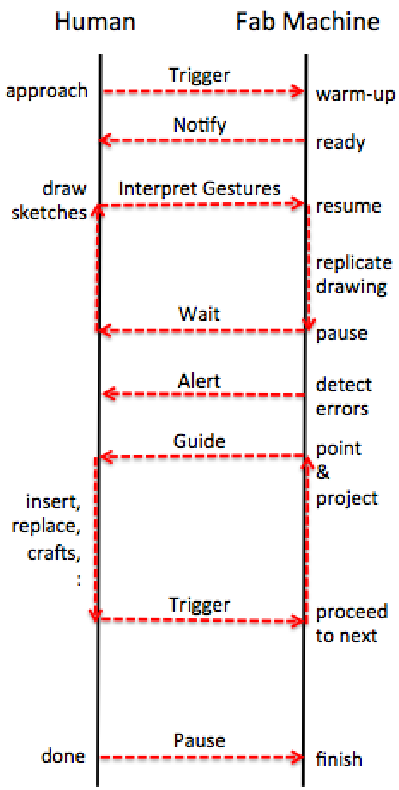

Figure 1. Possible exchange of taking leadership at each stage of the co-design process. From the preparation of the virtual model to having the final physical artifacts in hand, human and fabrication machine collaborate, dealing with problems, materials, and partial representation of outcomes.

in Figure 1) — restrict the in-the-wild design decisions that commonly occur as a work evolves from raw materials and hinders creative freedom.

Once the virtual model designed in CAD software is moved to the physical production phase, the human as a designer is in charge of all unexpected issues, physical dynamics, and potential failures. This pushes a user to validate their virtual design before it is sent to a machine, rather than allowing a human to ***trust*** the machines s/he works with. The mindset to have 'perfect' designs limits serendipity, happy accidents [7] and the meaning of the process itself [1], as well as in-the-wild improvisation. Unfortunately, a machine does not provide humans with any clues or agents about better decisions that might improve the quality of outcome, or affect the task stressfulness [5], which would give the designer more trust in the fabrication machine they work with as cohort.

Fabrication machines operate under their specific parameters, which control fine details of outcomes. Abnormal environmental conditions, alternative materials, etc., will change the expected end results. Yet, in the current uni-directional fabrication pipeline, limited communication between human and machine eliminates designers of the opportunity to interact with raw materials or partial outcomes of the final product, taking away the opportunity of reflective practices earned in action [6]. If often gets rid of the beauty and aesthetics that naturally evolve from handiwork and craft practice [1].

Imagine a robot working with a choreographer, artist, or music composer. A robot should be able to support their creativity arising from their improvisation, detecting and analyzing their meaning, reacting, and adapting dynamic changes into the current process. Such in-situ decisions coming from unexpected physical dynamics or changes in the designer's though process could be augmented by external input, from a mentor or creative colleagues with useful insights [2]; ideally, the high degree of computational precision could also be used to solve engineering problems. Unfortunately, as the processes that occur within fabrication machines are hidden within "black boxes", most designers and enthusiasts do not have the skills to operate such machinery regardless of their level of expertise and their domain knowledge [3].

Now we need an intelligence of supportive agent that is descriptive about the logic underlying its black box. This intelligence will allow segmenting tasks, human intervention, and the adaptation of outcomes generated by such intervention thanks to flexible, multi-directional task leadership switching (See Figure 1). There could be the right classification on the categories that a human can do well and/or a robot can do better [4], warning and suggesting based on robots' fast computational ability and precision should support, this on-the-fly design decisions to yield the best quality work.

Design Goals (RQs): Can a fabrication machine

- be a supportive robot, collaborative and informative, actively being engaged in a successful meeting of human's handwork and machine precision and compromise them?
- observe a designer's actions, following what s/he did when the task leadership is switched, analyze the partial representation of a temporal outcome, and provide sufficient information to improve it?

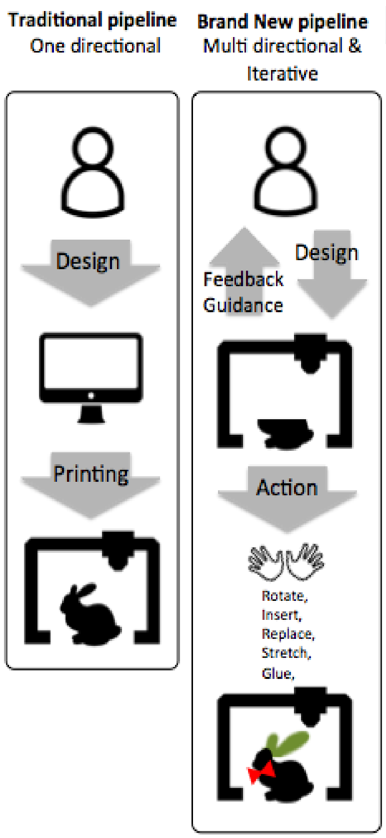

Figure 2. A re-imagination of 3D prinitng workflows within a novel human-fabrication machine interaction concept. This multi-directional process fuses the precision of the printer with the beauty of the human's handiwork to aid the design thinking in the middle of production, allowing free modification of a model with human intervention thanks to the robot's perception about the process, active analysis, and rich guidance.

- connect a person or other connected machines with the knowledge base, to help itself in case of a lack of intelligence?

We envision fabrication machines as colleagues that strive, not only to produce a physical object, but also to aid in creative work, exploring how the distinctive characteristics and capabilities of such technology can be exploited for collaborative and collegial efforts (e.g., ready to help in real time, guide a designer to precisely measure and conduct an action by computation, and support serendipity and exploration within the fabrication process).

This work aims to envision ***Human-FabMachine interaction (HFI)***, an multi-directional, interactive, concurrent, and creative collaboration between human and fabrication machines to harness the precision of digital fabrication and cultivate mixture of the beauty and serendipity, handicraft for material manipulation, and designers' critical design decision at the same time (Figure 2).

Imagining a Social Fabrication Robot

Inspired by three design goals, we imagine a social fabrication machine: a *Sensing Machine*. Envision a fabrication enthusiast, 3D printing a metal-handled vase. The printer uses its gesture-sensing capability to observe human movements in the middle of the process, interprets them, and converts them into machine code in real time. The person pauses the printing task in the middle of the process, and applies a metal handle, a foreign material made from the 3D printer to enhance aesthetics.—perhaps to enrich the presentation of the work, or to mechanically solidify the object. The printer realizes that this insertion creates a collision with tool paths for the rest of model; leading to the failure of the printing job. The printer alerts the human, requires the insertion of more scaffolding material to accommodate the result, or instead re-calculates paths for meshes to build the surrounding infill. When the human confirms the decision to apply new meshes, the printer cleans out the queue of previous tasks, and continues to complete the printing using the newly generated paths.

Implications for New Fabrication Pipeline

From the virtual scenario we derived, here we present three design implications for designing an interactive fabrication process:

<u>The Interaction Should Be Accessible:</u> When interacting with the fabrication machine in the middle of processes, designers should be able to intervene the machine process adaptively, anticipating concurrent task switching, without fear of losing control, or fear of ruining the final outcomes.

<u>The Control of a Task Should Be Shared by Each Side:</u> The process a designer gradually completes his creative works, should support a flexible exchange of human's decisions and a machine's computational precision to generate the best of quality at the end.

<u>A Pipeline Should Support Human-Problem Interaction:</u> A fabrication machine must be able to intelligently analyze problems might occur in the middle of the process because of continuous intervention, physical dynamics, to logically suggest options, and to reasonably provide guidance to aid designers' decisions, toward directly interacting with problems that arise given the condition in-situ

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