Enabling Ubiquitous Personal Fabrication by Deconstructing Established Notions of Artifact Modeling

Evgeny Stemasov
evgeny.stemasov@uni-ulm.de
Institute of Media Informatics, Ulm University
Ulm, Germany

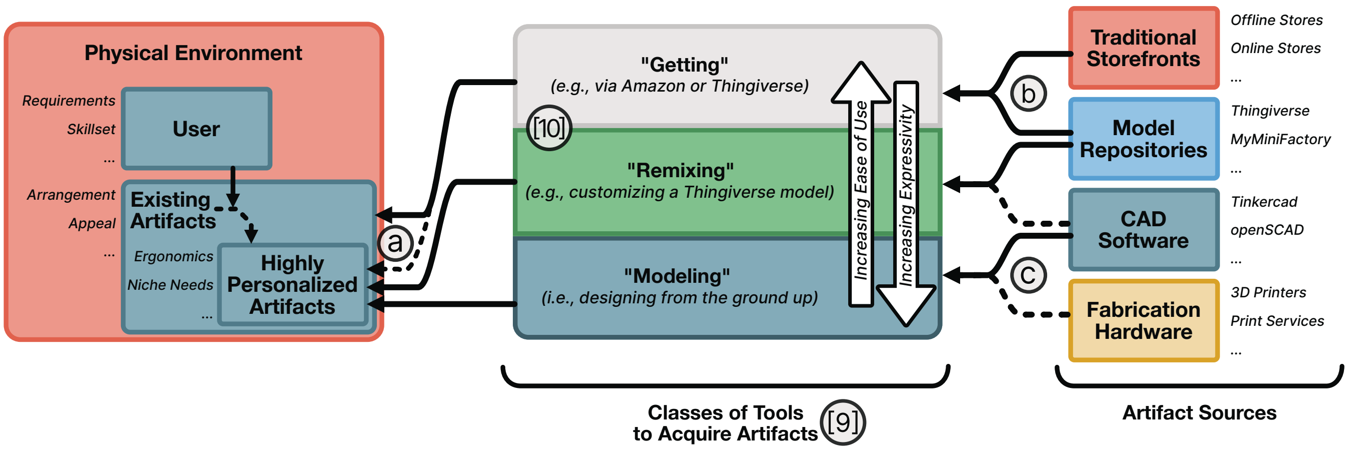

Figure 1: Ways of acquiring new physical artifacts as explored within the scope of my thesis. Most prior works in personal fabrication focus on simplifying modeling-like procedures (c). With my work, I want to focus on making shopping-like interfaces (b) more powerful, focusing on "getting" and "remixing" artifacts (a). This may make highly personalized artifacts more attainable for *non-hobbyist* users. In [9], we discussed different tool approaches, ranging from modeling, over remixing to "getting" artifacts. Store-like interfaces trade expressivity in favor of ease of use. Modeling interfaces invert this relationship. In [10], we presented an in-situ interface to a model repository, enriched with remixing functions (a).

ABSTRACT

With the notion of personal fabrication, users are handed industry-level processes to design and manufacture arbitrary physical artifacts. While personal fabrication is a powerful opportunity, it is currently employed by hobbyists and enthusiasts. Consumers, accounting for a majority of the population, still employ workflows like shopping to acquire physical artifacts. The core of my thesis focuses on partially or fully omitting steps of modeling, by relying on outsourced design effort, remixing, and low-effort interactions. Through such deliberate omission of workflow steps, the required effort can be reduced. Instead of starting "from scratch", users may remix existing designs, tune parametric designs or merely retrieve their desired artifacts. This moves processes in personal fabrication towards shopping-like interactions, away from complex but powerful industrial CAD (computer-aided design) systems. Instead of relegating design processes to a disconnected workstation, users may conduct search, remix, and preview procedures in-situ, at the location of use for the future artifact. This may simplify the transfer of requirements from the physical environment. Low-effort–high-expressivity fabrication workflows may not be easy to achieve, but crucial for widespread dissemination of personal fabrication. The broader vision behind my focus on "ubiquitous personal fabrication" is one where any person can create highly personalized artifacts that suit their unique aesthetic and functional needs, without having to define and model every single detail of the artifact.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

Personal Fabrication, In-situ Design Tools, Low-effort Personal Fabrication, Ubiquitous Personal Fabrication

ACM Reference Format:
Evgeny Stemasov. 2021. Enabling Ubiquitous Personal Fabrication by Deconstructing Established Notions of Artifact Modeling. In *The Adjunct Publication of the 34th Annual ACM Symposium on User Interface Software and Technology (UIST '21 Adjunct), October 10–14, 2021, Virtual Event, USA.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3474349.3477589

ACM ISBN 978-1-4503-8655-5/21/10.
https://doi.org/10.1145/3474349.3477589

1 INTRODUCTION

Devices like CNC mills, 3D printers, or laser cutters continue to become more powerful and affordable. They – along with associated software – are tools for creative expression and productive use alike. The increasing adoption of personal fabrication devices can be construed as *empowerment*: it allows users to create their own artifacts with industry-grade precision, instead of having to rely on off-the-shelf solutions. This applies to decorative items such as figurines, functional items such as furniture, or items that may have both decorative and functional purposes (e.g., planters). The capability to leverage industry-grade precision enables users to fulfill potentially any niche requirement.

However, both hard- and software carry an inheritance from their original use in industry contexts. They are often complex and hard to learn, as their original tasks have been similarly complex. To successfully leverage fabrication, effort is required. Technology enthusiasts, craftspeople, or hobbyist makers are willing to invest effort in the process, enjoying friction and explorations. On the other hand, consumers are willing to benefit from the results of personal fabrication (e.g., highly personalized artifacts), but are not necessarily willing to learn and engage with the (modeling) tools [5, 9]. My focus lies on the stage of "defining artifacts", which may happen through retrieval, remixing, or modeling, with each of these options offering distinct benefits (e.g., high precision and expressivity) and downsides (e.g., required effort).

With my PhD work, I explore novel takes on personal fabrication as a tool in future everyday life, ideally *beyond hobbyist/enthusiast use* [9, 10]. My approach to this is not merely focusing on a *"lower skill floor"* (compared to industrial CAD), but rather one that is *"as low as possible"*. Minimizing the skill floor requires rigorous *omission* of workflow steps, instead of their simplification. In particular, the omission of any step or task that is not crucial for a user's success: if no manual input by the user is crucial during fabrication, then the fabrication may be outsourced. If the user's requirements can be reduced to a single parameter, then a design tool should expose this single parameter only, while providing immediate feedback. Ideally, users should quickly receive feasible results, while retaining a high ceiling of expressivity. This calls for interactions similar to shopping and customizing products, less to established notions of 3D modeling. (3D) modeling artifacts can be seen as a highly expressive but potentially highly complex task used to "define a 3D artifact". Retrieving an artifact from a repository (e.g., Thingiverse or an online store) can be seen as a fairly easy task, given the right search methods, but is always bounded by the diversity of the repository. Remixing is a feasible middle ground: by relying on existing artifacts or features, users can fine-tune the degree of personalization they employ while customizing an artifact.

With my two first projects, I laid the theoretical foundation for my thesis (figure 1[9]) and developed an in-situ remixing tool (figure 1[10]). In [9], we were able to derive a continuum of modeling — remixing — getting, representing core approaches to physical artifact acquisition. To progress towards ubiquitous personal fabrication, several aspects are relevant to consider: 1) (3D-)modeling in its traditional sense should be reconsidered, as few artifacts must be defined from the ground up. Relying on automation, parametric designs, and remixing is a feasible way to reduce effort. 2) In-situ tools bridge the disconnect between design and use, simplifying the transfer of requirements from the physical context to the design. This doctoral symposium paper briefly introduces the works published so far, the vision behind the works I am pursuing, and offers brief insights into ongoing projects.

2 UBIQUITOUS PERSONAL FABRICATION

With my PhD work, I explore how and if HCI research may enable *Ubiquitous Personal Fabrication*. This term was originally introduced by Gershenfeld [3], but focuses on programmable matter and self-reproducing machines at large volume and high precision – "digital fabrication in everything" [3, p. 178]. The aspect I am most interested in is how we may **interact** with and control machines able to fabricate *anything*. In particular, the personal, consumer-oriented side is highly intriguing to consider, as it may enable any person to fulfill any reasonable requirement they may have for a physical artifact.

In "The Road to Ubiquitous Personal Fabrication" [9], we analyzed a set of recent systems for personal fabrication, which focused on "novice users". We discovered classes of systems outlining approaches to make artifact acquisition easier: in-situ tools, automation, repository interfaces, modality transfers, tangible modeling tools, and tools that follow modeling as a paradigm while simplifying it. A set of works was then arranged in a gradient between "getting" (shopping-like interfaces) and modeling (industry-grade

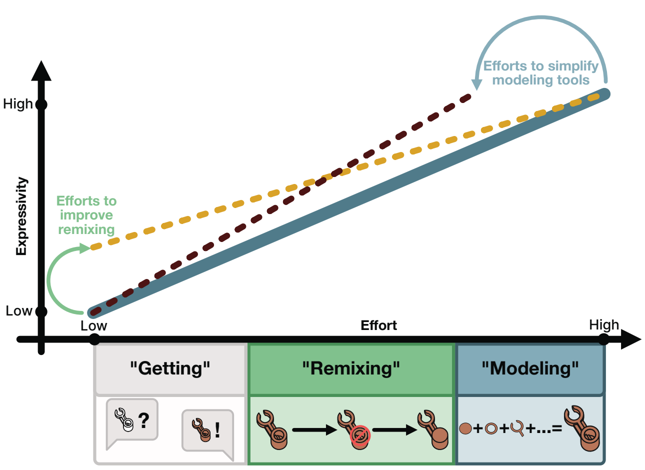

Figure 2: Investing high effort in a workflow generally leads to a high expressivity. Low effort generally implies a low expressivity of a workflow. We segment this range of effort, into interface focused on "getting", "remixing" or "modeling" physical artifacts. Simplified modeling tools may benefit hobbyists more, while improved store-like interfaces (e.g., through remixing) may be applicable to a broader audience (adapted from [9]).

CAD interfaces). The more an artifact acquisition process leverages derivative work, the closer it operates to "getting" artifacts (figure 2). The space between "getting a finished artifact" and "modeling an artifact from geometric primitives" can be labeled as "remixing", where at least some degree of work is omitted through the help of a system (e.g., it provides generators or assets to use in a design). Remixing is highly valuable, as it avoids modeling an artifact or partial features from scratch, while requiring the user to alter relevant parts of an existing design.

3 MIX&MATCH

Figure 3: Brief workflow with Mix&Match: a) search for hook designs, b) in-situ preview of an appealing design, while coarsely verifying function and scaling it to fit (remixing), c) evaluation of the 3D-printed result.

Mix&Match is a proof-of-concept implementation of a design tool that actively involves the user's physical context in the design process, while enabling the usage of outsourced designs [10]. This focus on outsourced designs ideally enables "modeling-free personal fabrication", where users do not have to engage in a modeling process. It focuses on 3D printing as a fabrication process, but could likewise be applied to other, similarly capable processes. Mix&Match facilitates the practice of in-situ remixing, where users – regardless of proficiency in modeling tools – may leverage outsourced designs and features found in their immediate vicinity to remix artifacts in the space they will be fabricated for. It embraces a set of aspects relevant for low-effort personal fabrication: 1) it relies on outsourced 3D designs (i.e., from MyMiniFactory[1]), and 2) work (i.e., previewing and remixing) happens in-situ, instead of at a disconnected workstation. A sample workflow can be seen in figure 3, where a user searches for a hook, previews it mounted to the shelf it will be fabricated for, and receives a fitting printed result.

Mix&Match can be considered a tool enabling real-world-remixing, as includes the user's physical environment in the remixing process. The user can not only preview a design in-context, but also alter it with the help of features in the environment itself (figure 4), if they have been scanned previously. For instance, users may copy already existing artifacts to fabricate in a different scale. They may also apply Boolean operations to the digital model, for instance, subtracting a real shelf from a flowerpot, to create a press-fit-like mounting geometry.

4 VISION

An intriguing thought experiment is to consider a scenario of a *"Fabrication Utopia"*. Imagine every piece of furniture being perfectly tailored for you, every piece of clothing being perfectly comfortable and matching your style. Imagine any mechanical task being solvable almost instantly – not with few design iterations, but in a single, brief attempt. Similarly, one may consider a *"Fabrication Dystopia"*: not one where manufacturing has retreated back to industrial uses, but rather one where it became thoughtless and wasteful [6]. With current consumer behavior in mind, systems for personal fabrication ought to embed sustainability in their interactions, instead of arguing for quicker design iterations. Likewise, personal fabrication should be applied to tasks, issues, or challenges where it *actually makes a difference* to highly optimized commercial processes. Balancing effort and expressivity is a challenge present in HCI-focused fabrication research [9], which is being addressed through different approaches (e.g., remixing, automation). The easiest tools may be merely interfaces to dispense a single type of artifact (e.g., Amazon's Dash buttons). The most complex tools may be highly expressive, but require months or years of education before users become proficient with them. Designing systems that are both highly expressive but require minuscule effort is a "wicked question" which may not be solvable in our time. However, it is feasible and highly intriguing to slowly nudge towards this extreme by developing and exploring novel ways of interacting with design and retrieval tools for physical artifacts.

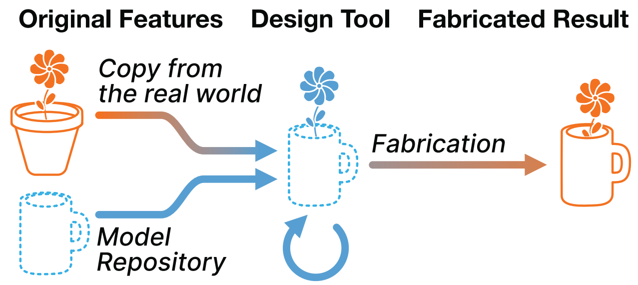

Figure 4: Mix&Match aims to enable "real-world-remixing" in-situ, where features or entire artifacts can be used for new designs to fabricate. If the physical environment of the user is scanned and segmented (e.g., through a mixed-reality HMD), it can serve as a source for features and artifacts, similarly to a digital repository (e.g., Thingiverse).

5 IN PROGRESS

With "The Road to Ubiquitous Personal Fabrication" [9], I have set a framework for my thesis, in which subsequent works can be arranged in. The following directions represent projects that my collaborators and I are currently working on.

▸ **Explorations of *Search***: An ongoing project is dealing with the search for physical artifacts. Similarly to modeling being the dominant paradigm for defining physical artifacts, textual search is dominant in repositories such as Thingiverse. This was also used by Mix&Match [10]. We explore alternative, in-situ methods that benefit from the user's physical context

▸ **Explorations of *Fidelity***: Personal digital fabrication was hailed as a way to bring industry-grade tooling and precision to

[1]https://www.myminifactory.com/, retrieved 25.6.21

hobbyists and consumers [1, 4]. While precision is a generally admirable property, requiring users to precisely express requirements necessitates effort. With this work, we explore workflows moving from low-resolution prototypes to higher-resolution ones.

► **Explorations of *Gamification and Play***: Prior works have applied game-like interfaces to facilitate learning of software [7]. In this project, we focus on handing manual craft and digital fabrication devices an active role in a board game, without enforcing a precise or productive use. This may be a valid entry point to fabrication for non-hobbyists (i.e., consumers).

► **Explorations of *Sustainability***: While a vision of ubiquitous personal fabrication may be tempting, it has to be considered on a society-scale, instead of an individual scale. With this work, we are currently exploring fictional effects of widespread, lowest-effort fabrication activities and how we, as a research community may consider sustainability in the systems we build.

These works have in common that they try to avoid established notions of how we approach personal fabrication, by leveraging situated interaction, tangible interaction, gamification, or other approaches that may trade some expressivity or precision for effortlessness. They do not enforce modeling-like interactions, but rather aim to circumvent them by augmenting retrieval (search), employing tangibility, or embedding fabrication in a playful context.

6 STATUS OF THE DISSERTATION

I have started my PhD work in October of 2018. In the fall of 2021, I will be beginning my fourth year of studies. Finalizing the projects outlined in section 5 is likely to take 1 to 2 years, without including the write-up of the thesis itself. From the doctoral symposium, I hope to gather new, critical perspectives on my work. This is crucial for determining the direction of the dissertation and the upcoming projects.

7 CONCLUSION & FUTURE WORK

My research aims to contribute new concepts for personal fabrication, venturing further away from the industrial origins of (digital) manufacturing. In particular, I aim to approach personal fabrication, not from the direction of "simpler-modeling" tools, but lowest-effort interfaces for artifact acquisition, omitting any step that is not crucial for the *end result*. This involves the development of such concepts [9] and the implementation of appropriate proof-of-concept prototype systems [10]. With the proof-of-concept systems, I would like to shift focus to lowest-effort tools, which may not be applicable to complex mechanical tasks, but rather mundane, everyday issues. In my research, I argue that such lowest-effort tools should not be simplified modeling tools, but should embrace procedures such as remixing or merely "getting" artifacts [9]. All kinds of tools may be feasible for the right combination of task and user. No one will reasonably design an airplane engine in Tinkercad[2]. However, one may still design a simple cloth hook in CATIA[3]. Assuming these two polar opposites of CAD tools, one may consider the user interacting with them. Hobbyists may both use simpler CAD tools such as Tinkercad, or venture towards more complex ones (e.g., CATIA). Consumers, on the other hand, will drift towards established processes to "get artifacts" – shopping, potentially iterating on the chosen design by returning products (i.e., physical artifacts) and ordering new ones. The process of "omitting workload" is relevant for non-users, novices, and experts alike, but moves to the background for users enjoying the process itself.

[2] https://www.tinkercad.com/, retrieved 4.8.21
[3] https://www.3ds.com/products-services/catia/, retrieved 4.8.21

I want to emphasize that personal fabrication research often seems to be about making hobbyists (i.e., existing users) more proficient. This is valid and promising. However, turning non-users into users is a similarly intriguing task. Looking at other content creation domains (e.g., photography) is highly relevant to understand how technologies became deeply embedded in everyday life, despite previously being limited to expert use [9]. Tools and communities such as Instagram have managed to turn large amounts of non-users of image editing into fairly proficient ones. While they may not be experts, many still actively and meaningfully *engage* with the technology (i.e., photography and image editing) on a daily basis.

While arguing for the widespread adoption of technologies and tools, societal impact is relevant to consider. Digital content creation in a purely virtual space may waste electricity. Physical content creation, however, may waste both energy and matter. Fabricating artifacts may be considered one part of Sutherland's "Ultimate Display"[11], i.e., it serves as an arbitrary, physical output. The "framerate" of this output is certainly not ideal but is continuously increasing, from one "frame" per day, to, someday, quick shape-changing artifacts. This raises the question, whether we, as a research community, want to hand a personal ultimate display to anyone, without restrictions. The value of highly personal, distributed **design** manifests in highly personalized artifacts fulfilling users' needs (e.g., clothing [8] or arbitrary attachments [2]. The value of distributed **fabrication** may be in easy access, which is more relevant for hobbyist users, over consumers.

Personal fabrication can become more than a hobby for technology enthusiasts and craftspeople. It can, at some point, become woven into everyday life, augmenting users' abilities, creativity, and ways of space-making, regardless of how niche (and therefore not economically feasible for commerce) a requirement may be. This may require casting off established notions of "modeling", and exploring alternative pathways to and definitions of success.

ACKNOWLEDGMENTS

I want to thank my supervisors and mentors Enrico Rukzio and Jan Gugenheimer for their guidance and unwavering support. I also thank my wonderful collaborators, who supported and inspired me in previous and upcoming projects.

REFERENCES

[1] Patrick Baudisch and Stefanie Mueller. 2017. Personal Fabrication. *Foundations and Trends® in Human–Computer Interaction* 10, 3–4 (May 2017), 165–293. https://doi.org/10.1561/1100000055
[2] Xiang 'Anthony' Chen, Jeeeun Kim, Jennifer Mankoff, Tovi Grossman, Stelian Coros, and Scott E. Hudson. 2016. Reprise: A Design Tool for Specifying, Generating, and Customizing 3D Printable Adaptations on Everyday Objects. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. ACM, New York, NY, USA, 29–39. https://doi.org/10.1145/2984511.2984512

[3] Neil Gershenfeld, Alan Gershenfeld, and Joel Cutcher-Gershenfeld. 2017. *Designing Reality: How to Survive and Thrive in the Third Digital Revolution.* Basic Books, Inc., USA.

[4] Neil A. Gershenfeld. 2005. *Fab: The Coming Revolution on Your Desktop–from Personal Computers to Personal Fabrication.* Basic Books (AZ), New York, NY, USA.

[5] Nathaniel Hudson, Celena Alcock, and Parmit K. Chilana. 2016. Understanding Newcomers to 3D Printing: Motivations, Workflows, and Barriers of Casual Makers. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16).* ACM, New York, NY, USA, 384–396. https://doi.org/10.1145/2858036.2858266

[6] Cindy Kohtala. 2017. Making "Making" Critical: How Sustainability Is Constituted in Fab Lab Ideology. *The Design Journal* 20, 3 (May 2017), 375–394. https://doi.org/10.1080/14606925.2016.1261504

[7] Ben Lafreniere and Tovi Grossman. 2018. Blocks-to-CAD: A Cross-Application Bridge from Minecraft to 3D Modeling. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18).* Association for Computing Machinery, New York, NY, USA, 637–648. https://doi.org/10.1145/3242587.3242602

[8] Daniel Saakes, Hui-Shyong Yeo, Seung-Tak Noh, Gyeol Han, and Woontack Woo. 2015. Mirror Mirror: An on-Body Clothing Design System. In *SIGGRAPH 2015: Studio (SIGGRAPH '15).* Association for Computing Machinery, New York, NY, USA, 1. https://doi.org/10.1145/2785585.2792691

[9] Evgeny Stemasov, Enrico Rukzio, and Jan Gugenheimer. 2021. The Road to Ubiquitous Personal Fabrication: Modeling-Free Instead of Increasingly Simple. *IEEE Pervasive Computing* 20, 1 (2021), 1–9. https://doi.org/10.1109/MPRV.2020.3029650

[10] Evgeny Stemasov, Tobias Wagner, Jan Gugenheimer, and Enrico Rukzio. 2020. Mix&Match: Towards Omitting Modelling Through In-Situ Remixing of Model Repository Artifacts in Mixed Reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20).* Association for Computing Machinery, Honolulu, HI, USA, 1–12. https://doi.org/10.1145/3313831.3376839

[11] Ivan Sutherland. 1965. The Ultimate Display. *Proceedings of IFIP Congress* 2, 2 (1965), 506–508.