Design Where and When Necessary – In-Situ Remixing for Prototyping Electronics*

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Digital fabrication combined with accessible electronics toolkits hands potential users an opportunity for unmatched creative expression: unique physical objects enriched with digital functionality, resulting in tangible, interactive, one-of-a-kind prototypes. These means are becoming increasingly affordable, but their reach often remains focused on enthusiast environments (i.e., hobbyists) or educational spaces. To increase the adoption and relevance of such toolkits, it is essential to consider the barriers faced not only by intrinsically motivated hobbyists, but also genuine non-users, who may gain motivation through their results, and less through friction in the process at first. The consideration of two aspects, present in design tools for manufacturing is valuable: 1) a **focus on remixing** existing designs to lower the required effort, and 2) **in-situ interaction** to allow for meaningful previews in the context for which prototypes are being built. With this position paper, we want to argue for the relevance, importance, and potential for situated, low-effort, and remixing-oriented workflows for the design of interactive artifacts. We first outline existing notions of remixing and in-situ design in adjacent domains, followed by a set of opportunities that can further the adoption of making across even wider user groups.

CCS CONCEPTS • Human-centered computing~Human computer interaction (HCI)

Additional Keywords and Phrases: Remixing, Prototyping, Crowdsourced Design, Low-Effort Design, In-Situ Remixing

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1 INTRODUCTION

The means for designing unique physical artifacts (e.g., manufacturing devices, prototyping platforms, and toolkits) are becoming increasingly accessible to broader audiences [1], and enable a rich space of expressivity [2]. While these manufacturing devices (e.g., 3D-Printers) and prototyping platforms (e.g., microcontroller ecosystems) are both affordable and reasonably accessible to motivated end-users, they often demand "design from scratch" – a process where users routinely design and re-design a majority of elements (e.g., enclosures, logic, wiring) that are relevant to their goals. Depending on the users' skill levels, this can be a lengthy and complex process, requiring them to acquire domain knowledge first and engage in trial-and-error. Neither the re-use of code/logic is directly part of most IDEs, nor is the re-use of mechanical elements part of most 3D-modeling environments, nor is the re-use of wiring elements (or finished wiring assemblies) part of most assembly approaches, as they try to balance expressiveness and genericity with simplicity. The design process is further decoupled from the users' physical environment (i.e., the one they are designing an artifact for), which requires them to engage in transfers [3], [4] between the design environment and use environment. Wiring and assembling prototypes is a physical act, while programming, for instance, resides in a mostly digital domain.

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The notion of "*modeling from scratch*" [1] can be circumvented by relying on platforms like hackster.io[1], or Autodesk Instructables[2], where entire projects are available to replicate or ***remix***. When observing the developments of domains such as music production, arts, and, more recently, 3D-printing, remixing emerges as a relevant catalyst for broader access to these content creation domains [5], [6]. In the context of end-user-designed electronics, this process is also present, but has little to no support through design tools and shared infrastructure. Remixing is crucial for novice users, but suffers from two shortcomings: the absence of remixing-focused tools to support users, and the aspect that wiring and assembly happen in-situ, yet remixing and programming happen at an often spatially and conceptually decoupled workstation.

In this position paper, we argue for this vision where a broad range of users will be enabled to **prototype when and where necessary**, engaging in active design and iteration to achieve ***unique*** behavior by leveraging in-situ interaction, previewing, and remixing of existing, openly available designs. This requires emerging design tools (and, by extension, ecosystems) to situate relevant activities in the relevant physical context and environment, and additionally, the improvement of ecosystems and databases to augment how end-users find and access designs to remix. We initially present definitions of remixing as found in arts and music, supporting them with their emergence and evolution in the maker domain of 3D printing. We then outline a set of opportunities and challenges we see with this direction.

2 VISION: ELECTRONICS DESIGN "WHEN AND WHERE NECESSARY"

Grounded in our previous works in the space of design for personal fabrication (Fig. 1), we argue that design activities for physical objects should be: a) based on existing designs where possible, instead of starting "*from scratch*", leaving users to explore novel spaces (***when** necessary*), and b) leverage the means of spatial computing (e.g., AR) to support users' design activities in-situ (***where** necessary*). The following section details this vision and how it may apply to the design of interactive physical artifacts – i.e., artifacts that combine several layers of components (e.g., logic, electronics, sensing) to enable novel, unique, and interactive functionalities.

Figure 1: In our prior works, we explored how 3D-printing may be supported through in-situ search and remixing of objects from a model repository (e.g., Thingiverse). Mix&Match (a) lets users preview designs in their future context and remix them [7]. ShapeFindAR (b) allows users to search for designs to 3D-print through rough sketches, vague keywords, and iterations with results [8].

2.1 Definitions of "Remixing"

As relevant as the notion of remixing is, it remains loosely defined, especially in contexts other than consumer media (e.g., music or visual arts). Yet, remixing is present in domains like programming [9] or end-user design and manufacturing [10], [11]. For media, Eduardo Navas formalized three distinct types of remixes: "extended" – prolonging media for other uses [12], "selective" – where material is added to or removed from a source [12], and "reflective" – more autonomous reimagining of an original [12]. The latter two variants are applicable to the design of objects and electronics, where users benefit from existing designs and are able to re-compose them component by component. In 3D-printing, alternative, more formal definitions were introduced by Flath et al. [5]: merges, compilations, retrospects, forks, bouquets, and, specifically

[1] https://www.hackster.io/, accessed 17.2.2023
[2] https://www.instructables.com/, accessed 17.2.2023

related to Thingiverse, customizer remixes [5]. Despite originating from other domains, the aforementioned types apply and are relevant to multi-component designs that unify different layers of functionality, like shape, behavior, and electronics. Interactive physical artifacts are an example of such designs. Remixing's applicability becomes particularly relevant when we consider users' efforts to achieve their desired results [1]: can they leverage existing functionality and re-combine and augment it to fulfill their needs? Or, do they have to re-create and re-design assemblies only to reach their desired starting point for their design? This ties into the work of Kyriakou et al., who identified re-use for replication, innovation, and customization [13].

2.2 State of the Art in Electronics Remixing: Ex-Situ and Enabled Implicitly

Platforms like Instructables, Hackster.io, or GitHub are crucial to enable remixing of electronics-related projects. This also applies to example code found in library documentation, samples, or project writeups scattered across individual makers' personal webpages and blogs. The underlying paradigm is one focused on sharing and enabling replication. Notably, not only purely technical detail is shared, but also parts of the experience, struggles, and issues found in hard- and software. While these resources enable replication, they are not tailored towards remixing: it is complex to find and adjust the right parameters, as it requires diving deep into the code and architecture of others. Replicating the assembly and wiring of such a found prototype is then the first step, preceding any remixing activity.

2.3 Opportunities

We consider the paradigms of in-situ design and remixing to provide opportunities for electronics design and prototyping. 3D-design is already a crucial part used in conjunction with electronics prototyping itself. We believe that design tools for personal fabrication, currently focused on the design of static artifacts, can serve as a source for paradigms and co-evolve with the design tools for electronics and interactive artifacts. Specifically, they may do so by replacing laborious recreation of existing projects or elements with creative explorations that build upon prior designs. This is already being done today but is not woven into the tools we use to design and program interactive artifacts. Additionally, situating design and exploration within the physical context we are designing artifacts for, can support users with visualizing and modeling interactions with the environment. Both aspects are relevant for a broader dissemination of electronics design across the population; ultimately including people beyond technology enthusiasts.

Addressing the following challenges—discussed in the next section—through novel design tools may facilitate broader access not only to the *tools* and frameworks for electronics prototyping, but to novel, innovative, and exciting *outcomes* that emerge from them if adopted by a broad range of users.

3 CHALLENGES

The following paragraphs list a set of challenges that we see – beyond specific applications and interface implementations.

3.1 Balancing Expressivity and Simplicity

Emerging design tools for electronics design and prototyping that are situated in more digital contexts have to strike a balance between expressivity and simplicity. While the output space of these design tools is virtually infinite, managing complexity remains a crucial challenge and opportunity to enhance accessibility. Retrieval interfaces may reduce effort, but do so at the expense of expressivity [1], therefore demanding meaningful ways to design and remix from existing designs and templates [7]. Similar tradeoffs are necessary for parametric configurators or interfaces that constrain the output space of designs in a comparable fashion.

3.2 Encoding Metadata and Search

In addition to suitable tools, remixing further needs the right infrastructure to be a valuable addition to the space. How do users find designs that they may remix? How do they encode the desired functionality, and how is this mapped to existing designs? For 3D-printing, we explored this with ShapeFindAR [8], where users searched for 3D-models through in-situ sketches combined with text and supported through machine-generated labels. This line of thought can be followed for interactive objects: how do users encode behavior, functions, and interactivity in a search query? Approaches like design by demonstration [14], or copy-and-paste [7], [11] are ways to reduce the effort needed to achieve the desired results.

3.3 Attribution

The more remixing becomes a part of a design process, the more relevant proper attribution and provenance become. When designs (of objects, circuits, functions, etc.) are re-used in new ones, preserving attribution becomes a highly relevant aspect of design tools and infrastructure [15]. This gets challenging when users are dealing with artifacts that were designed and altered across "long chains" of remixes, where remixes tie in large amounts of ideas from other objects, or where the remixing relationship is less of a technical nature, but rather a conceptually inspirational one [5].

3.4 "Desirable Difficulty" and the Importance of the Process

While lowering effort is a reasonable goal to make the domain more accessible, it may be seen as in opposition to genuine learning and exploration that sharpens the skills of makers. Experiencing friction is part of the process and is a moment for explicit learning. In this context, it is crucial to consider whether the user is focused on the outcome of the resulting artifact [16]. Both approaches have their value, yet complex processes full of potential friction are embraced by manufacturers, a focus on outcomes, in turn, is left to online commerce [1], where the untapped potential for widespread adoption may lie.

4 CONCLUSION

Remixing was proven to be a valuable catalyst in both innovation and access. It is already present in the context of electronics design: through openly shared designs that end-users can replicate and adapt if needed. However, this process of remixing leaves room for improvement: we argue that we need to provide low-effort ways [17] for users to reach their goals while actively embedding their unique physical environments into their remixing or design processes. This can be supported through two distinct yet interconnected directions that we deem relevant: 1) leveraging **spatial computing** (e.g., AR) to situate design and remixing in the context of use and 2) enhancing and enriching the **infrastructure** for makers to share [18], remix [19], and donate [20] back to the ecosystem. Radically lowering entry barriers to making by omitting workflow steps [1] is bound to make the process more accessible and turn even more non-users into capable, creative designers of innovative artifacts, devices, and tools.

BIOGRAPHIES

Evgeny Stemasov is a final-year PhD candidate in the Human-Computer-Interaction Group at Ulm University, headed by Prof. Dr. Enrico Rukzio. His works focus on the ''wicked problem'' of low-effort yet highly expressive design tools and processes for personal fabrication. To explore this, he has developed and evaluated in-situ design tools leveraging remixing, crowds, mixed reality, or tangible interaction. During his PhD, he was active as an instructor for fundamentals of HCI, taught courses on hardware prototyping, worked as a freelance developer, and interned at Autodesk Research in Toronto. His academic works have been published at venues like ACM CHI, UIST, TEI, and IEEE Pervasive Computing.

Ali Askari is a first-year PhD student at the Institute of Media Informatics at Ulm University, Germany. During his time as an undergraduate student, he worked as a research assistant at the institute and supported several research projects in the automotive domain. With his passion for physical prototyping, he focused on hardware-heavy projects. After graduation, Ali started his PhD in the field of HCI with a focus on Augmented-Reality in cooperation with the BMW Group, Munich. He took over the lead organization of the course "Sketching with Hardware" at Ulm University, which aims to teach prototyping to computer science and media informatics students. Extra-professionally, Ali founded a small solo business, which focuses on supporting museums and other public facilities with the realization of 3D printing projects and interactive concepts.

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