Principles of maker and DIY fabrication: Enabling design prototypes at low cost

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Do-It-Yourself (DIY) fabrication is the practice where the end user creates a product for personal use rather than commercial production. This paper reviews how DIY practitioners can produce useful artefacts with limited resources. Fabrication principles were extracted from the DIY design repository Instructables.com. A set of candidate principles was iteratively refined and converged to five unique principles. Case studies are presented that illustrate approaches for implementing each. A first empirical study verifies the repeatability of the principle classification through crowd-sourced assessment. A hypothesis is that the principles seen in DIY fabrication can support design prototyping. This is validated through an empirical study that shows a positive correlation between exposure to the principles and enhanced design outcome.

Keywords: prototypes, design practice, distributed design, case studies, social design

Prototyping is critical to success in the early stages of design. For example, projects without a working prototype are rarely funded on the incubation platform Kickstarter.com. Empirical design research of prototyping has provided: strategic methods (Camburn, Dunlap et al., 2015; Menold, Jablokow, & Simpson, 2017); effects of timing efforts (Elsen, Häggman, Honda, & Yang, 2012; Faas, Bao, & Yang, 2014; Häggman, Honda, & Yang, 2013, Neeley Jr, Lim, Zhu & Yang 2013; Yang, 2005); outcomes of process techniques such as iteration or parallel prototyping (Dow et al., 2010); and studies of fixation (Viswanathan and Linsey 2010, 2011; Youmans, 2011). Existing methods provide high level planning of the prototyping process. There is substantial opportunity to explore the fabrication of prototypes. Knowledge of means to reduce effort and improve build quality of prototypes would complement existing research. What then, are principle techniques of successful prototype fabrication? One avenue for exploring this question is to review emergent do-it-yourself (DIY) design repositories. These repositories are unique as they provide freely accessible documentation of the development process. This work follows a systematic review of the open-source database Instructables.com, to extract principle means of fabrication. The demographics, socio-economic implications, and origins of the of

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do-it-yourself (DIY) movement have been established in other works (Anderson, 2012; Kuznetsov & Paulos, 2010; Paulos, 2013; Triggs, 2006). A research area of potential interest to designers are overlaps in context faced by DIY developers and those faced by designers and engineers engaged in prototyping for new product, service, and system development. Herein, a prototype is defined as a pre-production functional representation of some aspect of a product service or system. These overlaps may include: exploration of a technology that is novel to the maker, limited resources, limited time, limited equipment for fabrication, and a requirement to establish basic proof of concept functionality rather than to deliver a commercial product as-is.

1 *The Do-It-Yourself design movement*

What is DIY design? DIY design is typically implemented outside of the framework of professional design, for the purpose of practical gain (Edwards, 2006). It may often be an individual activity, however sharing communities have recently evolved (Rosner & Bean, 2009). Although research suggests that DIY communities are social in origin (Triggs, 2006), there are currently numerous platforms which are highly technology oriented. Information moves organically in these communities. Experts may seed forums with extensive topic knowledge (Torrey, Churchill, & McDonald, 2009). This exchange can directly lead to the mutual benefit of participants (Salmond, 1997). In turn, a forum of creativity is emerging where open-sharing is highly valued (Kuznetsov & Paulos, 2010). The paradigm permits individuals a self-reliance to modify or develop certain technologies (Atkinson, 2006). It is possible for individuals without a technical background to fabricate a cellphone, or other complex tools (Mellis & Buechley, 2014). This does not eliminate the need for large-scale manufacture of basic components; however, it does act to democratize innovation through information sharing (Mellis & Buechley, 2014). DIY development can share benefits of craft such as high quality aesthetic (Arnheim, 1994). The opportunity is much greater than this alone, genuine technological advancements are within the scope of non-experts (Atkinson, 2006).

What opportunities does the DIY movement present for design research? Often in a traditional design scope, needs assessment is conducted in partial isolation from the user (Reich, Konda, Monarch, Levy, & Subrahmanian, 1996). For DIY projects, the designer is often also the final user. Open sharing permits iterative evolution as each participant advances a design to fit their needs (Saakes, 2009). The development of personal fabrication also provides a novel design arena. Open-source part databases (e.g. Thingiverse, Shapeways), in combination with free modelling software (Mota, 2011), and low cost digital manufacture (3D printers or laser cutters) make design and fabrication of geometrically complex parts a desktop activity (Mota, 2011). Distributed manufacturing networks (e.g. Alibaba) provide means of accessing

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