Research Prototypes

Ilpo Koskinen[1*], Joep Frens[2]

[1] School of Design, Hong Kong Polytechnic University, Hong Kong

[2] Department of Industrial Design, Eindhoven University of Technology, Netherlands

Abstract

Background Prototyping has become a key research tool in product and interaction design during the last twenty years. There is a growing debate about its processes, objectives, qualities, and types. This paper contributes to this discussion by distinguishing research prototypes from design prototypes and industrial prototypes, and by analyzing debate about research prototypes.

Methods The primary method of the paper is theoretical literature review. The paper analyzes literature and its implications to research prototyping. The secondary method of the paper is a case study of a well-known research prototype built by Joep Frens (2006).

Results The main result of the paper is a clarification of research prototype and how it differs from design and industrial prototypes. Research prototypes have a connection to a theory rather than practice. Because of that connection, they are theoretical objects that have to be subjected to a study to understand their meaning. Although the methodology for studying prototypes may vary depending on the philosophical background of researchers, this paper argues that it is this embeddedness to theory that is the differentia specifica of research prototypes.

Conclusions If the argument of this paper is correct, research prototypes are objects of their own, and have to be understood as such rather than put to the same continuum as design and industrial prototypes.

Keywords Design research, prototyping, research through design, constructive design research

*Corresponding author: Ilpo Koskinen (ikkoski@polyu.edu.hk)

Citation:

http://dx.doi.org/10.15187/adr.2017.05.30.2.47

Received : Feb. 21. 2017 **; Reviewed :** Mar. 07. 2017 ; **Accepted :** Mar. 27. 2017
pISSN 1226-8046 **eISSN** 2288-2987

1. Background of the Study

There has been quite a bit of discussion about prototyping in recent design research. This has been the case in particular in the area of research through design or constructive design research. Here design rather than research is the key tool for producing knowledge. The assumption is that to produce knowledge, it is not enough to describe, explain or predict things or people as in the sciences and the social sciences. Rather, the assumption is constructive: the knowledge resides in objects and in the design process of these objects (see Hengeveld, Deckers and Frens, 2016).

There has also been lots of discussion about prototypes and their status in design research during the last twenty years. The crucial device of constructive design research, after all, is a design process, which culminates into a product-like prototype. As it sometimes happens in design research, the early efforts in clarifying the concept of prototyping borrowed heavily from engineering and concentrated in classifying prototypes and their meanings. For his PhD thesis, industrial designer Simo Sade (2001) classified prototypes on a scale from low-tech prototypes in early phases of product development to high-fidelity prototypes typical to the later phases. His study identifies three functions of prototypes: idea generation, communication, and testing on a continuum from exploration to risk management (Sade, 2001: 51, 55). Architects, furniture designers and transportation designers talk about "models" rather than prototypes (Moon, 2005; Morris, 2006). For all of them, prototypes "filter" the design space by helping to focus on appearance, functionality and interactivity, as Lim et al (2008) have noted. Recently there have been several calls for increased fidelity to make prototypes more product-like (Odom et al, 2016).

While earlier literature about prototyping largely came from HCI, engineering or industrial practice, the last ten years have seen a series of attempts to understand prototyping in design research. Zimmerman et al. (2007) distinguished design artifacts from research artifacts that are aimed at producing knowledge, and divided the former into philosophical and grounded types. The latter are inspired by real world problems, the former by theory. These philosophical artifacts can be physical manifestations of theory, or more typically, theoretical explorations of its consequences. Wensveen and Matthews (2014) distinguish four roles for prototypes in design research: they can be experimental components, means of inquiry, a research archetype (as in critical design, where they are exemplary and ostensive), or vehicles of inquiry, akin to research methods. Somewhere between industrial practice and research are "experience prototypes" that create an experience that can be studied (Buchenau and Fulton Suri, 2000), and its elaboration into "prototyping social action" by Kurvinen et al. (2008) (for a catalogue, see Mikkonen, 2016) and recent extensions of prototyping into services (Meroni and Sangiorgi, 2011).In a recent article, Stappers and his colleagues note that design research progresses probably more by prototypes and frameworks than "through an academic research agenda with grand theories and questions," and see this as a deficiency in comparison to more mature disciplines, thus leaving open how they contribute to design research (Stappers et al., 2014: 170-171).

As this discussion suggests, prototypes are built for many purposes, and the purpose determines how they are done. Prototypes done in design research differ from design prototypes in design firms and also from industrial prototypes. Design prototypes typically explore forms, structures, manufacturability, materials, and so forth. They typically capture only those aspects of products that are relevant to finishing the design, but leave out other things like the details of electronics and an exact specification of materials. Industrial prototypes, in their part, are closer to the definition of a prototype as the first in a series. They are almost fully finished, manufactured with techniques in factory production, and as they approximate a future product, they try to cover most of the aspects relevant to products. As recent literature suggests, research prototypes differ from design prototypes and from industrial prototypes. What kinds of creatures are they? What are their aims, differentia specifica, and how are they built to respond to the needs of design research?

2. Research prototyping

The most important difference between research prototypes and other types of prototypes is purpose and the connection to theoretical literature. The purpose of research prototypes is to articulate and test concepts that respond to questions from theoretical literature at the bottom or a research program rather than product development. Because of the connection to theory, research prototypes are tested in the light of this theory rather than in the light of things on the marketplace, manufacturability or product safety, as in the case in industrial and design prototypes. In research prototyping, the vehicle that helps researchers to select a reduced number of variables for their study is theoretical work. Contrasting to other types of prototypes, research prototypes are the 'end-point' of the (design-research) process, the prototypes do not 'prototype' a final product, system or service. This leads Odom et al. to introduce the term 'research product' (Odom et al., 2016) as the end point of a constructive design research process. As this term is not adopted in the research community and our argument hinges also around the verb 'prototyping,' we continue to use the word 'prototype' in this article.

Previous theoretical work has two main functions in terms of prototyping. The first is the way theory helps to select what to build. Variation is wide. At one end are 'grounded' projects (Zimmerman et al., 2007), in which a real world problem often suggests the research vehicles and theory comes after the fact. At the other end are theory-driven 'philosophical' projects, which have more freedom of choice because theory as a rule does not tell what to build, but only where to direct the search. In this freedom of choice hides one of the critical challenges of constructive design research: when prototyping, unanticipated phenomena and insights enrich the research challenge and often lead to a rephrasing of the research question. The drawback is that the outcomes are often difficult to predict, their repeatability is low, and questions regarding the generalizability of the knowledge and insights can be damaging. The prize is that theory-inspired prototyping processes are open enough to deal with 'wicked problems' that cannot be partitioned to independent sub-problems. This is the normal function of theory in research: it is a tool that helps when other solutions do not work.

The second function is methodological. Again, we face a wide variety of practices (see Koskinen et al., 2011). For some, it takes the form of laboratory experiments. The boldest statements of this kind go back to Kees Overbeeke and people he mentored, most notably Caroline Hummels, who argued that design should produce conditional rather than general laws (2000: 65). In this interpretation, prototypes have to be well designed, but they also have to make it possible to vary those variables that are crucial to the underlying theoretical argument:

> Design research resembles research in, e.g., psychology in that it has a minimum of controls built in when exploring the solution when testing variations of solutions. Therefore ... "we have kept the devices simple, pure and with resembling aesthetic appearance." This makes it possible, to a certain degree, to isolate and even manipulate systematically critical variables. (Overbeeke et al., 2006: 63–64).

For others, prototypes are things to be followed rather than tested (for example, Koskinen et al., 2006; Kurvinen et al., 2008; Judice, 2014; Odom et al., 2016). Here prototypes open possibilities for action, and it is the action that design researchers follow. Behind this is the notion of indexicality from Garfinkel (1967)[1]. This interpretation builds on Buchenau and Fulton Suri's (2000) concept of experience prototypes, and has affinities to Ehn's recent claim that design "things" are like parliaments that bring people together to make decisions (Binder et al., 2011). For yet others, research prototypes are things that embody ideas in a provocative form so that people can debate these ideas (Bell et al., 2005; Beaver et al., 2009). The essential thing is an imaginative approach to an issue or belief, and a provocative attitude to prototyping. For instance, the idea of energy harvesting at home may turn into a study of biomass, and lead to a prototype of a table that eats mice, as in James Auger's work (2012). Prototypes become connectors that force people to ask where they would like to set the boundaries of technology.

3. Rich interaction camera and its theoretical background

Our example of research prototyping comes from the PhD work on Rich Interaction of Joep Frens (2006), supervised by Kees Overbeeke and Tom Djajadiningrat. His work was of the 'philosophical' variety and aimed to explore consequences of theory for design. The group around Overbeeke found their theoretical basis in Ecological Perception by James Gibson (1972) (e.g., Djajadiningrat et al., 2002; Hummels, 2000; Wensveen, 2004; Ross, 2008). Frens was interested in exploring an alternative interaction style for consumer products inspired by the theory of Ecological Perception and added insights from research on Tangible Interaction as a second theoretical pillar to inform his work. He aimed to find an alternative to the menu-based interaction style that was (and is) paramount in the interactive products of the day. He chose a digital camera as his research vehicle to constrain his design-based exploration. His theoretical starting point together with his choice for research vehicle informed and constrained his arena for design.

1) Crabtree (2004) has likened prototypes to Garfinkel' s breaching experiments.

In his design process Frens chose to refrain from traditional paper sketching and explore the challenge though a cardboard modeling technique (Frens, 2016), thus adding another constraint to his design process. He intuited that a physical interaction style (as informed by the two theoretical starting points) was best explored in the physical immediately rather than through representation on paper. This designer-based exploration led to a series of camera designs sporting alternative interaction styles, all in cardboard and foam-core models. One of these cameras was chosen for further inquiry and renamed 'rich actions camera'. It was used in an exploratory experiment that compared the rich actions camera to a more conventional camera (both as cardboard models).

This experiment pointed two things out: (1) it is best to evaluate interaction styles by means of working prototypes (as opposed to cardboard models) and (2) the differences in form of the two stimuli was biasing the evaluation of interaction style. Responding to these insights Frens decided to: (1) make a fully working prototype of the rich actions camera in a more robust material and (2) make this working prototype modular so that it could accept interface modules that featured different interaction styles ranging from the original 'rich' interaction style to a more conventional interaction style.

In the process that followed a new prototype was made. Frens decided to use an existing camera (Canon PowershotA60) as the functional basis for his new prototype. The camera was taken apart and modified such that its controls could be operated by an external microcontroller through reed-relays (attempts to access the camera hardware to an API proved to be unsatisfactory). This was done through a series of partial prototypes specifically meant to fine-tune and optimize the functional parts for the camera. The dimensions of the restacked functional parts were driving the dimensions of the new prototype; as a result the new prototype was 125% of the size of the original cardboard model. Next to the size difference there was a change in how zoom functionality was operated (the original design had a telescoping lens, the new prototype featured a zoom ring). Also the new prototype connected by means of an umbilical cable to a small box that was worn in a bag over the shoulder that contained a microcontroller and the batteries. A final difference with the original design was that the new prototype was made modular to be able to incorporate different interface modules to vary interaction style. To this end four different interface modules were design and made. These modules were systematically varied from rich interaction to conventional interaction. To switch a module the screen of the camera had to be un-mounted from the one module and remounted into the next module.

With the fully operational, aluminum 'rich actions camera' an experiment was conducted in a lab setting. 24 participants (architecture students) used the four different interaction styles (in counterbalanced order) in a photo studio. They were 'guided' through the interaction by means of a carefully phrased assignment of taking and reviewing pictures of a still life. Pre and post use measurements were taken using Hassenzahl's product qualities framework (2004). At the end the participants were asked to rank the camera's from ugly to beautiful, from bad to good, and from hard-to-use to easy-to-use. Next to this the participants were asked for preference for actions in the cameras and classic usability measures were taken. The results were analyzed and Frens found that the rich interaction style scored similar on

classic usability to the more conventional interaction style. Next to this, the rich actions camera scored high on preference. From this Frens concluded that the rich interaction style was a viable alternative to the more conventional interaction style.

4. The camera as an object of research

The main purpose of Frens'sstudy was to study the implications of Gibson's theory and tangible interaction to design. His study built on a set of precedents that were mostly done in the same research group he was working. Earlier work had a more theoretical character and had focused on virtual reality, but his study expanded it into the domain of product design. The outcome of the study was a physical camera, which, however, was not the end product of the process. As the purpose of the study was to generate a better understanding of the possibilities of rich interaction, Frens had to demonstrate whether his design interpretation of Gibsonian theory works or not. This he did through a series of user tests.

The camera was designed and tested in the lab to explore the qualities of an alternative interaction style that was informed by theory; it explored the consequences of theory in product design. It is important to note that the camera was not meant to test aspects of the theories it used for inspiration, it was meant to showcase an alternative interaction style and consequently to learn about its qualities. Arguably, many other questions could have been asked, testing many other variables. For the main part this was not done for the very pragmatic reason that a PhD project is, at some point, finished. There is one type of questions that the camera cannot answer and we want to single those out. This type of questions concerns the testing of variables pertaining to the camera as a product. The camera is a research prototype with enough product qualities as to be a meaningful informant of design practice but it is ultimately not a product nor was it meant to be a product. Throughout the process of its conception it was driven by a research question, considerations with regard to context of use, manufacturing, andeven user needs were left out. This sets it apart from a design prototype that emphasizes very different values. In that light it is also clear that it was not an industrial prototype either, it was not meant to test the optimization of electronics, the functioning of mechanics or product safety.

Reflecting on the work that was done in light of the topic of research prototypes it is clear that while the camera is inspired by theory there is not a recipe-like message to be gleaned from the camera of how to design with its theoretical basis in mind (J. J. Gibson's ecological perception and its derivatives in tangible interaction). Elements of the design can be pin-pointed to be a direct result of the theoretical positioning but the camera is more than a series of physicalized insights, it also is a designed entity that tests how far we can bring theory but also finds the boundaries of theory. Next to this it is important to recognize that not every aspect of the design of the camera was the result of theoretical positioning, practical aspects like fitting camera parts or the overhead of making the camera modular had influence on the design of the camera as well.

In the previous paragraph we observed that the prototype in Frens's work was a research prototype and not a design prototype or an industrial prototype. We coupled this to the intention of the work and the 'production' values of the prototype. Yet, we feel that in the process we have seen instances of design prototypes and industrial prototypes that were instrumental for the construction of the final research prototype. The first cardboard model can be regarded as a design prototype that informed the final prototype. The prototypes that were used to fine-tune the operation of the functional parts can be seen as industrial prototypes.

5. Discussion

This paper has distinguished research prototypes from design prototypes and industrial prototypes. If the paper is correct, their defining criterion is connection to theory. There has been a lot of debate about prototyping in design research (see Sade, 2001; Wensveen and Matthews, 2014; Stappers et al., 2014; Hengeveld et al., 2016; Odom et al., 2016), but as far as we can say, this line has not been clear. Recent debate about research-through-design has pointed out that prototypes in research are vehicles of knowledge production (Zimmerman et al., 2007, 2010), but many of the implications of this issue have been left open in debate. This ambiguity has led to both conceptual and practical confusions about prototyping.

Our conceptual vehicle has been the distinction between design prototyping, industrial prototyping and research prototyping. These are different activities if we are correct. All build on a product development process, but put stress on different things. In design prototyping, the attention goes to appearance or functionality, benchmarks are existing products, critique is the usual method of examining the outcomes, and the outcome is a model that can serve as a base for a product. In industrial prototyping, where product tests take various forms, including sometimes user tests benchmarks are existing products, but the main goal is a product, not knowledge of how the concept behind it works, which is also the case in design prototyping. In research prototyping, the crucial variables come from theory instead, and to know what the prototype teaches about theory, it has to be tested, typically with users, as Zimmerman (2007)has noted with his colleagues.

Our example of a research prototype has been Joep Frens's rich interaction camera (Frens, 2006), which he built to test a theory of rich interaction. This notion had its roots in J. J. Gibson's ecological psychology and in earlier work of the Designing the Quality of Interaction group at TU Eindhoven. After building a model of what rich interaction could be, Frens went through a design process, which ended with a camera that turned the notion of rich interaction into a physical prototype. The endpoint of his research was a series of user studies with the camera aimed at testing the theory rather than qualities the industry or a design consultancy would have been interested in like manufacturability, usability, the look and feel of the camera, the details of the interface, or the optimal location of the microcontroller.

We have argued that one conclusion from this paper is that research prototypes are objects of their own. They are not deficient versions of design or industrial prototypes. One implication of our argument is that the quality of the prototype is a secondary issue as long as it is good enough for serving as a vehicle in knowledge production. Usually, research prototypes are done with relatively cheap materials, shortcut technology, and remain short-lived. More often than not, they typically also require the presence of the designer to function, often using Wizard-of-Oz techniques (see Rasmussen, 2015).

How the dual connection to theory happens most likely depends on researchers' theoretical and methodological preferences. In Frens's study, the methodology came from experimental psychology (see Overbeeke et al., 2006), but in other studies, the methodology has built on fieldwork (Koskinen et al., 2006; Rasmussen, 2015) for instance. Regardless of methodological variation, however, the connection to theory remains constant: it directs work researchers are doing, shapes the prototype in crucial aspects, and leads to work that produced claims of knowledge for other students to question. The duality is to be found in how the design work is both inspired by theory but, in turn, also instrumental in forming theory.

If we are correct, our main recommendation is to pay attention more to theoretical issues and evaluation in prototyping. We are aware of the fact that this goes somewhat against some recent calls to make prototypes more product-like (Odom et al., 2016). This may be required to capture user experience in long-lasting field studies. There is, however, a trade-off between high fidelity and theory. High fidelity may lead people to mistake prototypes for products, which designers usually want to avoid until very late in design to avoid giving getting trivial feedback about the product's lok and feel when it is not yet necessary. In design practice, these issues are explored with appearance models, look-alike products that are, however technologically so sketchy that the line between product and prototype remains easy to observe even for non-designers.

One question the reviewers of this paper raised was about the limitations of our work. Our paper has focused on a very specific context, design research as it is practiced today in industrial design and interaction design programs in design schools (and to some extent in IT industry). This paper is not a philosophical statement aimed to go beyond this context. Looking at this context shows some limits to our argument, though. Most notably, recent work in service and community design prototypes social organizations that are defined by people who participate in them. While Frens (2006) was able to treat his camera as a stimulus in his experiments, it would have been extraordinarily difficult to control a farmer's market inNutrire Milano (see Meroni and Sangiorgi, 2011; Kurvinen et al. 2008 have voiced the argument for open designs sharply in their crowdsourcine-type study), or fly-eating robots meant to provoke debate in Why Robot? (Auger 2012).This observation, however, would lead us from a conceptual to a methodological study, which is outside the scope of this paper.

References

1. Auger, J. H. (2012). *Why Robot? Speculative Design, the Domestication of Technology and the Considered Future* (Doctoral dissertation, Royal College of Art, London, 2012). Retrieved March 3, 2015, from http://researchonline.rca.ac.uk/1660/.
2. Beaver, J., Kerridge, T., & Pennington, S. (2009). *Material beliefs*. Goldsmiths, University of London/ Interaction Research Studio. Retrieved March 5, 2010, from http://materialbeliefs.co.uk.
3. Bell, G., Blythe, M., &Sengers, P. (2005). Making by making strange: Defamiliarization and the design of domestic technologies. *ACM Transactions on Computer-Human Interaction, 12*(2), 149-173.
4. Binder, T., De Michelis, G., Ehn, P., Jacucci, G., Linde, P. & Wagner, I. (2011). Design things. Cambridge, MA: MIT.
5. Buchenau, M., & Suri, J. F. (2000, August). Experience prototyping. In *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 424-433). ACM.
6. Crabtree, A. (2004, August). Design in the absence of practice: breaching experiments. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 59-68). ACM.
7. Djajadiningrat, T., Overbeeke, K., & Wensveen, S. (2002, June). But how, Donald, tell us how?: on the creation of meaning in interaction design through feedforward and inherent feedback. In *Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 285-291). ACM.
8. Frens, J. J. (2006). D*esigning for rich interaction. Integrating form, interaction, and function*. Eindhoven, the Netherlands: Department of Industrial Design.
9. Frens, J. J. (2016). Cardboard Modeling: Exploring, Experiencing and Communicating. In *Collaboration in Creative Design* (pp. 149-177). Springer International Publishing.
10. Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs, NJ: Prentice-Hall.
11. Gibson, J. J. (1972). A Theory of Direct Visual Perception. In J. Royce, W. Rozenboom (eds.). The Psychology of Knowing. New York: Gordon & Breach.
12. Hassenzahl, M. (2004). The Interplay of beauty, goodness, and usability in interactive products. *Human-computer interaction, 19*(4), 319-349.
13. Hengeveld, B., Frens, J., & Deckers, E. (2016). Artefact Matters. *The Design Journal, 19*(2), 323-337.
14. Hummels, C. (2000). *Gestural design tools: Prototypes, experiments and scenarios*. Delft, the Netherlands: Delft University of Technology.
15. Judice, A. (2014). Design for hope: Designing health information in Vila Rosario. Helsinki: UIAH.
16. Koskinen, I., Kuusela, K., Battarbee, K., Soronen, A., Mayra, F., Mikkonen, J., & Zakrzewski, M. (2006, June). Morphome: a constructive field study of proactive information technology in the home. In Proceedings of the 6th Conference on Designing interactive Systems (pp. 179-188). ACM.
17. Koskinen, I., Zimmerman, J., Binder, T., Redstrom, J., & Wensveen, S. (2011). *Design research through practice: From the lab, field, and showroom*. Elsevier.
18. Kurvinen, E., Koskinen, I., & Battarbee, K. (2008). Prototyping social interaction. *Design Issues*, *24*(3), 46-57.
19. Lim, Y. K., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 15(2), 7.
20. Meroni, A., & Sangiorgi, D. (2011). *Design for services*. Gower Publishing, Ltd..
21. Mikkonen, J. (2016). *Prototyping Interactions*. Tampere: Tampereenteknillinenyliopisto – Tampere University of Technology.

22. Moon, K. (2005). *Modeling messages. The architect and the model*. New York: The Monacelli Press.
23. Morris, M. (2006). *Models: Architecture and the miniature*. Chichester, UK: Wiley.
24. Odom, W., Wakkary, R., Lim, Y. K., Desjardins, A., Hengeveld, B., & Banks, R. (2016, May). From research prototype to research product. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 2549–2561). ACM.
25. Overbeeke, K., Wensveen, S., & Hummels, C. (2006, November). Design research: Generating knowledge through doing. In *Proceedings of the 3rd Symposium of Design Research: Drawing New Territories* (pp. 51–69).
26. Rasmussen, M. Kirkegaard (2015). *Shape-Changing Interfaces*. Aarhus: University of Aarhus.
27. Ross, P. (2008). *Ethics and aesthetics in intelligent product and system design*. Eindhoven, the Netherlands: Technishe Universiteit Eindhoven.
28. Sade, S. (2001). *Cardboard mock-ups and conversations*. Helsinki: UIAH.
29. Stappers, P. J., Visser, F. S., & Keller, A. I. (2014). The role of prototypes and frameworks for structuring explorations by research through design. In Rodgers, P., and Yee, J. (eds). Routledge Companion to Design Research. Florence, KY, USA: Routledge, 2014: 163–174.
30. Wensveen, S. (2004). *A tangibility approach to affective interaction.* Delft, the Netherlands: Delft University of Technology.
31. Wensveen, S. & Matthews, B. (2014). Prototypes and prototyping in design research. In Rodgers, P., and Yee, J. (eds). Routledge Companion to Design Research. Florence, KY, USA: Routledge, 2014: 262–276.
32. Zimmerman, J., Forlizzi, J., & Evenson, S. (2007, April). Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 493–502). ACM.
33. Zimmerman, J., Stolterman, E., & Forlizzi, J. (2010, August). An analysis and critique of Research through Design: towards a formalization of a research approach. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (pp. 310–319). ACM.