Chapter 7
Final Considerations on Prototypes in Design Research

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Abstract The study Paride presented in this book was developed by a team of researchers from the Department of Design of Politecnico di Milano. The aim was to have a general understanding of how the role of prototypes in design research is evolving. The investigation started with the literature review and analysis that let us frame a general overview of the matter, later examined through interviews with experts and a collection of case studies. We concluded that the general role of prototypes in design research is to support the transition from abstract concepts to defined design solutions. Prototypes can be used in specific phases of the research process to reach particular aims throughout the design research process. Prototypes are *purposeful* and *transient* objects made to concretize a conceptual idea. Playing these roles and reaching these aims, prototypes can support the generation of new knowledge—about and beyond the prototype itself—that can be translated into theoretical findings. These roles are evolving with the availability and integration of advanced technologies and the development of design discipline that is broadening and finalizing fields of research, methodology, and tools. The study had some limitations given to the time and extent of the investigation and other starting options on the approach. Nevertheless, during the research, we also came across some interesting extra insights, aside from the central topic of our discourse, that are worth mentioning and considering for further development.

7.1 Considerations from the Making of the Framework

Our study aimed to observe how prototypes are applied in design research to determine their role today. We assumed that the traditional role it played in the industrial manufacturing process—that of being "the first type of a mass-produced product" changed. Thus, we collected publications about prototype definitions (Blackwell 2015; Erlhoff and Marshall 2008; Geller et al. 2007) and prototype applications in

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design research (Valentine 2013), looking for insights from different design disciplinary areas allowing us to include inputs from other disciplines, such as engineering (Camburn et al. 2017; Moultrie 2015; Schrage 2013), where prototypes are used as well.

At first, we aimed to choose one definition of the prototype that would suit and guide our study, but we found it more interesting to leave this definition open. Indeed, we found out that *prototype* has different meanings among different disciplinary communities and even within a smaller context such as a single company. Furthermore, other terms—models, probs, artifacts, to mention a few—might have the same meaning of prototype in different contexts of use. Since we did not want to miss inputs, we collected any publication that would mention *prototypes* and similar terms aiming at having an encompassing overview (Houkes and Vermaas 2010; Koskinen et al. 2011; Gaver et al. 1999; Nimkulrat 2009). We embraced the indetermination of the data rather than trying to systematize it.

We started our study by collecting, reading, and analyzing the literature (Paré and Kitsiou 2017). We used two parallel approaches to it. On one side is a systematic collection of data, and on the other is the application of the Grounded Theory (Braun and Clarke 2006; Morse et al. 2009).

During the reading of publications, we found that the general contribution that prototypes could have in design research could be resumed in two primary roles. Traditionally, prototypes have brought ideas to life before manufacturing by testing a product's function, performance, and visual features. In this perspective, the prototype's role was to build knowledge *about the prototype itself* (i.e., function, performance, and looks). While today, prototypes are often used to generate new knowledge to reach an understanding at a higher general level that goes beyond the product under development, *beyond the prototype itself*.

Furthermore, we realised that every prototype is made to achieve a specific purpose throughout different phases of the design research process. After playing for such a purpose, prototypes might even be discharged. We collected all those specific aims and grouped them into nine main ones: develop, assess, communicate, comprehend, investigate, explore, provoke and envision.

Moreover, when reading the literature, we understood that beyond the general role of the prototype and specific aims, a set of categorization criteria (discipline, terminology, context, fidelity, and phase of the process) could frame the use of prototypes in the intention of the reference's author. We used these criteria to read and summarize all the publications, collect data in the case studies, and visualize them in our interactive tool.

After reading the literature and summarizing it in our Cards (see Sect. 2.1.3), we applied Grounded Theory Methodology to analyse it (Wolfswinkel et al. 2013). This bottom-up approach lets us understand the phenomenon summarised in four theoretical concepts.

Concept 1, "Transitions," referred to the understanding that the prototypes' role in design research is to support making embryonic ideas concrete through varied forms of representations and artefacts. Thus, enabling a *transition* from vagueness to clarity characterizes all views on the role of prototypes which dot the diverse landscape of

design research. Various research areas understand and achieve the transition in different ways. We detected two opposite poles: on the one hand, speculative and intangible, and material and realistic on the other.

Concept 2, "Making Theory," through prototyping, is the most significant aspect of an updated way of conceiving the role of prototypes in the field of design research, whether purely academic or practice-oriented. It implies prototyping to develop new theoretical knowledge. This vision is already shared in the design research community.

Concept 3, "Evolution," referred to the fact that while traditionally, prototypes have been means to bring concepts of new products to life before manufacturing, today, they are going through a radical change, just like the design discipline is. The impact of embedded technology and advanced manufacturing processes, on one side, and the broadening of design discipline on the other, are at the base of this trend that involves the evolution of prototypes too.

Concept 4, "Milieu," highlighted the fact that the role of the prototype has evolved hand in hand with the context in which it is applied. In this regard, the development of design, like an academic discipline, marked a fundamental step in the evolution of the prototype. The context in which the research takes place frames the role of the prototype more than any other criteria, determining the research purpose, methodology, phases, and, thus, all the specific aims for which prototypes will be applied in the process.

Overall, we can conclude that the general role of prototypes in design research is to support the transition from abstract concepts to defined design solutions.

Prototypes can be used in specific phases of the research process to reach particular aims throughout the design research process.

Prototypes are *purposeful* and *transient* objects made to move on in the process of concretizing a conceptual idea into a design solution.

They can support such transition in any design process, from purely speculative to practice-oriented studies. To do so, they can be of any nature—physical, realistic, intangible, or fictional—as long as they give an appropriate provisional form to the design ideas being developed.

Playing these roles and reaching these aims, prototypes can support the generation of new knowledge—about and beyond the prototype itself—that can be translated into theoretical findings (Stappers et al. 2014; Stappers and Giaccardi 2017; Mäkelä 2007; Niedderer 2013; Wakkary et al. 2015; Zimmerman et al. 2007).

These roles are evolving with the availability and integration of advanced technologies and the development of the design discipline that is broadening and finalizing fields of research, approaches, and tools (Bleecker 2009; Dunne and Raby 2013; Fraser and Seaton 2013; Kimbell and Bailey 2017; Kamrani and Nasr 2010). Also, the academization of design discipline is one phenomenon determining the role of prototypes in design research.

7.2 Considerations from the Application of the Framework

After reading and analyzing the literature and defining our framework, we shared it with experts. We collected their feedback on the theoretical concepts and a case study of their design research with prototypes. Meanwhile, we developed an interactive tool to help us visualize the relationships between the criteria describing the prototypes and the research they belong to.

In the tool, we made a research area divided into four quadrants that let us point out if the research was about something tangible or intangible (left and right quadrants) and if the research's general aim was speculative or concrete (top and bottom quadrants). Mapping the Case Studies, we noticed that doctoral theses are in the top part. The studies for industrial partners can be at the top or bottom, depending on whether the design proposal is fictional or realistic. Design consultancies tend to be in the bottom part even though nowadays they might develop fictional designs answering speculative questions, ending up in the top quadrants.

Many Case Studies are in the middle of the tangible and intangible areas because they represent research where the interactive feature of the design is predominant. This understanding generated some discussion (see Sect. 7.2.1).

The tool also showed the trends of the prototypes used in different phases of the research. In most Case Studies, all the research phases appear within the same quadrants and present a descending trend. Yet we noticed that in some Case Studies, there is the last phase where prototypes concur in communicating and discussing, thus ending up in a higher place in the tool's quadrants.

That reading confirms that, in general, the purpose of the prototype is to support the design process from abstractness to concreteness. Also, prototypes are used today for later final reflection and theorization phases.

We gathered a general agreement from all experts about the four theoretical concepts. Yet some interesting considerations arose during the interviews.

7.2.1 Tangible Transition or Not?

All experts agreed about the design process being described as a transition from abstractness to concreteness that prototypes concur to enable. When we asked if this transition should be through a material, tangible object, most experts said that, in their experiences, that would be the case. This consideration depends on the design area they belong to. As said, they all work in an area close to product design and interaction. Yet most of them also reflected that in other design fields, for instance Service Design (Blomkvist 2014), this transition could go through intangible means, such as experiences prototyped by visual tools or storytelling (Johnson 2011; Kirby 2010). So, they confirm our understanding that physicality is no longer a fundamental requisite for the prototype.

Also, some experts added that they might include in their design process: conceptual phases, where they use basic visual representations of their ideas (sketches, draft two and three-dimensional hand drawings or digital models, flowcharts, etc.), and communication phases, where they use storyboards, refined two and three-dimensional digital models, videos, etc. So, we agreed that those phases could be considered *intangible transitions* within the design of tangible objects. Yet we realized that examining the concept of physicality and intangibility in design today leads to further discussions, as in Sect. 7.2.2.

7.2.2 Are Visual Representation Tools Prototypes?

In literature, we could find several authors declaring or implying that representation tools belong to a different object category than prototypes (Hallgrimsson 2012; Lim et al. 2008; Pei et al. 2011; Yang and Epstein 2005). Indeed, this approach follows a more classical interpretation of design tools. Some objects visually represent concepts (like all drawings do), some let us interact with them (like models and probes do). The materiality of the object makes the essential difference in this categorization. In this reading, as the first ones are more passive and the second more interactive, they play different roles in the process. Visual objects are suitable for developing and communicating ideas, while physical objects can be tested, experimented on, experienced, etc. (Barati et al. 2017; Houde and Hill 1997).

This categorization is standard and appears reasonable but is put to the test by current phenomena.

Indeed, the fact that many products are now smart (Raff et al. 2020) means that it is necessary to use prototypes that anticipate the interaction in the design process. These objects might be paper prototypes, videos, simplified interactive applications, virtual representations of the product with simulated interactive features, and other things that imply an interaction. The interaction consists mainly of the user accessing visual information and operating manually (for instance, reading a screen and using buttons to select options). In this perspective, it is difficult, and perhaps pointless, to define whether this interaction is tangible or not.

Secondly, some experts commented that visual representations, such as storyboards, flowcharts, task analysis, mood boards, and other visual items, can be used to develop, share, anticipate, evaluate, investigate, and shape ideas of—for instance—interactions and experiences. In this perspective, the visual objects support achieving all the research phases, just like prototypes do. So, regarding the purposes, visual objects fulfill the same as prototypes. From this perspective, merging the categories (visual tools and prototypes) makes sense, as we did in our framework.

Furthermore, we witnessed the application of virtual experiences (Volino et al. 2015; Stjepanovič et al. 2017) in the design process to show clients the product to be. The development of virtual prototyping solutions started decades ago and is considered a promising solution to substitute many physical prototypes (Harms et al. 2009). Indeed, it is already so if we think the renderings, photomontages, videos, and

all digital objects that replace physical versions applied in today's design process. So far, physical prototypes that support tangible interaction need to be real, not virtual. Yet, we are witnessing that in recent years the latest virtual systems are starting to be used—we saw that in three case studies—to let users experience the interaction with the new solution in a completely immersive virtual environment. The experts told us that those virtual experiences were not as efficient as they had hoped, but they commented that they expect them to advance and help anticipate and test their designs.

After all, categorizing *visual* or *tangible* objects is not as relevant. Categorizing into *passive* or *interactive* and *real* or *virtual* prototypes seems more relevant.

7.2.3 Fidelity, a Concept to Count On or Not?

When reading the literature, we came across several authors who referred to *fidelity* to describe prototypes (Hallgrimsson 2012; Lim et al. 2008; McElroy 2016). Fidelity defines how close the prototype is to the finished products. Most commonly, it refers to the look and feels aspects, but it can also refer to functions, performance, and interaction. Usually, it is qualified by the low–medium–high level to grade the approximation to the final object: from simple draft mock-ups to refined working prototypes. Very often, the fidelity level is associated with the design process phase. Two observations arose from the debate with the experts.

Firstly, we tend to imply that the first creative steps of the design process need low-fidelity models, and the final stages require high-fidelity ones. Stappers, let us reflect on this matter by sharing this interesting insight. Once, he was talking to Bill Buxton, an important engineer in the field of Human–Computer Interaction. On that occasion, Stappers told him how they used to teach the students to do low-fidelity prototypes and high-fidelity ones. Buxton objected that there is no such thing as low and high fidelity. "There is only fidelity that is appropriate and inappropriate to the purpose of the model or implementation" (Greenberg and Buxton 2007). Stappers said that he appreciated this insight. He agreed that if you tell students to do low-fidelity prototypes first and then high-fidelity ones, they might think they can do sloppy work initially and later do it with effort. While it means that the prototype you do at the beginning has different aims than the prototype you do after.

Secondly, all the stakeholders involved in the process should be educated about the concept of fidelity. Colombo told us that when they developed a vision of possible futures for the partner company, they made high-fidelity models integrated with interactive simulations in a virtual experience (Colombo et al. 2018). The final prototypes seemed very real, even if they simulated the use of technology not yet available on the market. Thus, they had to explain to the clients that their solutions looked real but were fictional. This issue should be tackled soon to avoid disappointment.

Similarly, Meraviglia told us that nowadays, clients expect working prototypes from the beginning of the design process, adding that working prototypes and well-refined digital models might trick clients into thinking the product is almost ready

for manufacturing. So, he also stressed the point of educating the audience to avoid misunderstandings and create false expectations.

Thus, fidelity is a straightforward concept for designers that can lead to miscommunications if not appropriately used. We liked the suggestion to speak only of *appropriate* fidelity as it focuses on the aim: appropriate fidelity for the purpose of the prototype.

When interacting with other non-designers, emphasizing what the prototype is and represents is essential to reach a successful understanding and communication. This consideration will become more critical as real and fictional experiences mix, and all products' features will be realistically simulated in virtual environments.

7.3 Limits of the Study

The study was developed by a team of researchers from the same institution and the same disciplinary area of design (product and interaction design). A more varied team would have added at least some case studies in service and communication design, for instance, that would fill the II Quadrant of the interactive tool.

Then, during the research, we decided to have an encompassing approach and include all possible definitions of prototypes (or similar terms such as model, artefact, etc.) and any design research areas. The objective to achieve a broad view on the matter gave us a general understanding that might seem vague. A focus on specific disciplinary areas or contexts of research would reach a more precise definition of the prototypes and their role in such design research.

Also, after concluding the Paride study, we understood that we could pose some new questions to our experts. Indeed, we realized that the prototypes might have a marginal or central part in design research (and appear in just one phase or several phases of the process). So, in hindsight, we would also ask: "to what extent your research involves the use of prototypes?"

Furthermore, we realized that the definition of phases is relative to each research. Indeed, while the steps of product development product are quite consolidated among the design community, the phases of design research are not. So, we let the experts describe their case study's phases. We embraced this indetermination. As a result, the comparison among phases is not possible.

Eventually, while discussing the findings, we also realized that it is essential to consider the research level of development. In three cases, we found out that the expert shared a study that was later developed further. So, the general aim and use of prototypes could change. For instance, fictional research could be developed further to reach concrete results. On the contrary, a practice-oriented study could become part of speculative research, such as a doctoral thesis.

To conclude, in the discourse about the role prototypes in design research, it is necessary to consider the following:

- The disciplinary area and context of research.

- The extent of the usage of prototypes in the study.
- The level of development of the investigation.

The collection of Case Studies and their reading through the interactive tool did not let us generalize trends or rules because of the small number and the different results. Yet they helped us build a big picture of the phenomenon of prototypes' role in design research today.

7.4 Extra Considerations and Further Developments

During the research, we also came across some interesting extra insights that are worth mentioning as they widen the boundaries of our findings and could deserve additional investigation in the future.

7.4.1 When Does a Prototype Become a Finished Product?

Talking with the experts, we discussed the prototype definition, and some observations were raised, primarily referring to the traditional meaning of the prototype as the "first example of a new industrial product" as follows.

The example of Noronha is fascinating. Indeed, as said in Sect. 5.1.2 Noronha's objects are *unstable* because they can be seen differently depending on the context: they can be seen as medical prototypes, sculptures, or design products. They tell a story and can be exhibited in a gallery or a museum, and they can be taken either as finished objects or prototypes. Eventually, Noronha calls them *artefacts*. Indeed, those objects were sold to clients as *limited-edition artefacts*. Thus, they had a value and a market as art pieces for what they represented, while they also have been part of design research crossing the boundaries of medicine. In this case, an object can be simultaneously a finished product—a piece of art, a sculpture specifically—and a prototype of a prosthesis in speculative design research. This phenomenon, we reckon, can happen in design, a discipline traditionally close to art, and above all, it can happen to prototypes that are, as we said, purposeful *transient* objects, ready to change into something else or cease to exist.

Secondly, we discussed that digital products today, like programs, apps, etc., can be released on the market and updated when they are in the final users' hands. The user buys a finished product that keeps evolving. The updates are meant to improve the product. We wondered if those digital products are "finished" or "refined prototypes" that keep evolving over time. Although we could not find an answer to this, we reckon it is an interesting thought, mainly if we translate this concept to physical objects. In the past, industrial products were sold as "finished," but today, smart products can be updated by the manufacturer after the purchase. So, at least partially, this "unfinished" feature is entering the physical world. This idea had already developed

partially following the spreading of digital printing when maker movements and DIY enthusiasts imagined a future where physical products are self-made, customised, and repaired. We will see if this marginal approach will reach a mass market with products that can be updated, like the software. It could be good news for sustainability. We thought this could be an interesting matter to investigate further.

Referring to the discourse of virtual products, environments, and experiences, we also discussed the possibility that designers might design virtual products for the virtual market, such as the *metaverso*. This phenomenon already happens in the industry of games, where players can buy costumes, weapons, and all sorts of gadgets for their figures. These virtual objects can be updated without effort but with a cost. In this perspective, designers would make products that will never have to stand the proof of becoming real, will be constantly improvable, and thus, be potentially *transient* forever.

These discussion topics depend on the boundaries of design disciplines, traditionally close to technological and artistic areas but also open to crossing new ones and merging with others. They represent areas of future development for design prototypes.

7.4.2 Always Make Use of Prototypes or Not?

We came across another interesting topic of discussion that would need further investigation. Most of the interviewed experts pointed out the necessity of prototyping as a design research method. That is not a surprise since we chose them for their research approach, which implied the use of prototypes. But some stressed this point. For instance, Ayala-García said, "it is mandatory to use prototyping as a tool. Not a tool to refine ideas, but a tool to construct ideas. It is, in my opinion, one of the "secret tools" of the discipline" (Sect. 4.1.2). Indeed, we reckon that most authors in the literature consider prototyping an essential methodology of the design process. Prototypes are part of the design DNA. Yet, Kerspern's alert caught our attention. He said that in some academic and professional contexts, designers make prototypes because they are taught and expected to. They might do it blindly and superficially because it is part of the design process. This vision seems to contradict our definition of the prototype being *purposeful* objects. True is that the research's purpose sets the prototype's purpose. Making prototypes might not be valuable if not part of a worthwhile project. Design and researchers should take the time to set the research's objective, methodology, phases, and tools. The prototype should be a meaningful act of meaningful research.

7.5 Final Recap

Overall, we concluded that:

- The general role of prototypes in design research is to support the transition from abstract concepts to defined design solutions.
- Prototypes can support such transition in any design process, from purely speculative to practice-oriented studies.
- Prototypes can be of any nature—physical, realistic, intangible, or fictional—as long as they give an appropriate provisional form to the design ideas being developed.
- A set of criteria can describe prototypes and their use in design research. Among such criteria, the *aim* is the most important.
- Prototypes can support the generation of new knowledge—*about* and *beyond* the prototype itself—that can be translated into theoretical findings.
- These roles are evolving with the availability and integration of advanced technologies and the development of the design discipline that is broadening and finalizing fields of research, approaches, and tools.

We started our research understanding that it was worthless to look for an encompassing definition of prototypes that would apply to all disciplinary fields and converge all meanings. Thus, we accepted that due to the term prototype's open meaning, our investigation's boundaries were fuzzy. Nevertheless, we ended up finding one that at least applies to the design field:

> In design, prototypes are *intentional* and *transient* objects made to concretize a conceptual idea.

Furthermore, we shared other considerations on prototypes in design research.

In the design community, it is accepted that the transition from abstract to concrete enabled by prototypes can be by tangible and intangible means.

When interacting with other non-designers, emphasizing what the prototype is and represents is essential to reach a successful understanding and communication.

Making prototypes might not be a valuable activity in itself. It is always the research's purpose that sets the prototype's purpose. In other words, the prototype can play a meaningful role in meaningful research.

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