3. Making use of the research framework

Silvia D. Ferraris and Francesco Isgrò

Abstract The main objective of this research phase was to validate the findings of the first part of the research and to develop a framework for the role of prototypes in design research. We decided to validate our results by sharing them outside our research group to gather feedback and deepen the discussion. Thus, we interviewed nine researchers and practitioners in the design field. We shared our four theoretical concepts with them and collected their opinions, which we later shared among the research team members. Additionally, we asked the interviewees to share a case study of one of their research projects where the prototype played a relevant role. We asked for a short description of the research and prototype using the set of categorization criteria developed in the analytical phase of the study. The collection of these data proved to be valuable and complex. We anticipated the existence of interesting relations among the criteria. Therefore, we made an interactive visual tool that enabled us to discover and highlight such relationships. For instance, we highlighted the relationship between the context and research aim or between the prototype's nature and the research phase. Eventually, as a discussion tool, it let us observe our data and elicited further debate. Through this research phase, we developed our general understanding of the phenomena.

3.1 Case studies framed through an interactive tool

3.1.1 Setting the second phase of the research

The main objectives of this research phase were to validate the findings of the first part of the research and to develop a framework for the role of prototypes in design research.

The findings of the first part can be summed up in:

- There is no universal definition of the prototype in the design community.
- It is possible to define a prototype through a set of categorisation criteria (aims, discipline, terminology, context, fidelity, phase of the process).
- Traditionally the role of prototypes is to support the production of specific knowledge *about the prototype itself* to support the design process.
- In design research today, prototypes also support the production of theoretical knowledge *beyond the prototype itself*.
- Four theoretical concepts synthetize our understanding of the relevant phenomena that concern the role of prototypes in research today "Transition," "Making theory," "Academisation," and "Milieu" (see Sect. 2.2.4).

We decided to validate our findings by sharing them outside our research group and gathering feedback and case studies. We planned interviews with nine researchers and practitioners in the design field. We shared the four theoretical concepts with them and asked their opinion on our findings using a list of given questions. Then, we shared the outcome of the interviews among the research team members.

Also, we asked the interviewees to share with us, if possible, a case study of one of their research projects where the prototype played a relevant role.

At first, we asked them where they worked, proposing to option among four contexts ("Practice," "Practice + research," "Research + Practice," to "Academia", as defined in Sect. 2.1.2). Reflecting on this request, some interviewees told us that they worked across two of them. We recorded this input for further discussion on the relevance of the context in which the research takes place.

Secondly, we asked which disciplinary area they identified their work, and we let them give open answers. These questions helped us frame the context where the case study took place.

Thirdly, we asked for general information about the project research, such as name, period, other partners or people involved, and their role in the project/research.
Fourthly, we asked for a short description of the project research focusing on the role of prototypes in it. In addition, we used the set of categorisation criteria (defined in Sect. 2.1.2) to collect data about the case study. Thus, we asked:

- About "Terminology": all terms they remember using other than "prototype".
- About "Phase of the process": if they applied the prototypes in a specific phase of the process (giving the option among "conceptualization," "design development," "detailing," and "before production", as defined in Sect. 2.1.2);
- About "Fidelity": if they used this concept when describing their prototypes (giving the option among "low," "medium," "high," or "implicit," as defined in Sect 2.1.2);
- About the "Aims," we gave them our list of aims and sub-aims (see Sect. 2.3.1) and let them select the ones that applied to make their prototypes.

Hence, the data collection format strictly referred to the criteria we identified during the literature review.

3.1.2 Selection of interviewees and case studies

All the authors contributed with their research interests and specific disciplinary point of view in the research. As said, we all share an interest in product design, its material aspects, and its interaction with the user. Some researchers are interested in fictional or experiential approaches (see Chap. 5). Some are interested in interactive aspects of product design (see Chap. 4). Some focus on industrial design, design innovation, and design engineering (see Chap. 6).

We do purely *academic* research and research with external partners (industrial, public, etc.). Thus, as regards our definition of the context, we belong to "Research+Practice" and "Academic Research" (Sect. 2.1.2).

Hence, we selected nine experts from research universities and design consultancies to collect academic and not academic input, as planned from the beginning. Hereafter we introduce them briefly to explain the analysis and framework, while more extensive descriptions and insights will follow in Chapters 4, 5, and 6.

Case Study 1. Interviewee: Sara Colombo, Ph.D. At the time of the interview, she was a research project lead at MIT Design Lab. She is now an Assistant Professor at the Eindhoven University of Technology, NL.

Disciplinary Area: Design

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

Context: Research + Practice and Academic Research

Research: “Augmented health and safety: Future Vision”

In brief: This project was developed in collaboration with a worldwide energy company. The aim was to foresee how emerging technologies might integrate the energy industry’s health and safety approaches. The near future vision would support change and encourage the development and adoption of innovative solutions. The design fiction approach chosen for the research was based on designing and prototyping an ecosystem of physical and digital solutions. These new technology-based designs anticipated a vision of managing health and safety practices in future scenarios and triggered discussion among all stakeholders. (Colombo et al. 2018). This research presents an example of the collaboration between an academic research center and an industrial partner to develop a new vision through design fiction.

Case Study 2. Interviewee: Marco Meraviglia, Cefriel S.Cons.R.L. Milan

Disciplinary Area: Design & Engineering

Context: Practice + Research

Research: “Hemomix MILANO”

In brief: The project aimed to develop a new device for blood collection monitoring. The tool monitors the safety and the steps of the donation. It has a scale function, weighing the collected blood, and a mixing function that avoids blood coagulation. The project was done in collaboration with the company Delcon to meet the requirements of the New York Blood Center. The user-centered approach enabled the designers to make a new concept worth the Compasso d’oro Award in 2022. This research presents an example of the collaboration among three parts: design and engineer experts, the industrial developer, and end users (the medical center in this case) to develop an innovative industrial product.

Case Study 3. Interviewee: Bastien Kerspern, Co-Founder of Design Friction, Nantes, France

Disciplinary Area: Design Fiction and Speculative Design

Context: Practice + Research

Research project “The Rules for the Game for the Smart Streets”

In brief: Performing a prospective crash-test of citizens’ recommendations framing smart street experiments to adapt these propositions of rules in return. This research was conducted in the form of three organized workshops involving citizens and participants from local areas. This participatory approach ambitioned to collectively define a set of recommendations regulating the experiments of new technologies and new uses taking place in the public space on Nantes Island. This methodology of prospective and critic evaluation demonstrates how this design fiction approach can participate in a more extensive collaborative innovation process. This research also presents an example of the collaboration between a design consultancy and an urban planning and development bureau.

Case Study 4. Interviewee: Pieter Jan Stappers, Professor of Design Techniques at Department Industrial Design, section Conceptualization and Communication, TU Delft, the Netherlands

Disciplinary Area: Design Engineering

Context: Research + Practice and Academic Research

Research: Keller's TRI and CABINET PhD Thesis "FOR INSPIRATION ONLY. Designer Interaction with Informal Collections of Visual Material" by Adriaan Ianus Keller.

In brief: This research looked at how designers collected visual materials to inspire their design process. The aim was to support designers in this process by combining electronic and physical images. To this end, the researcher developed two prototyped solutions: a platform for exploring design tools using a sketchy variety of virtual reality techniques and a tool that merges virtual and physical images into one seamless collection. The prototypes could be experienced dynamically and interactively; thus, they could be tested by users and actively used for research. Theory and practice were integrated into this process thanks to the application of working prototypes used as research means to demonstrate and explore theoretical hypotheses. The author reported and analysed the whole research project. Then he generalised his findings. This research represented a crucial example of both Research through Design and Research for Design (Stappers et al. 2014).

Case Study 5. Interviewee: Livia Tenuta, PhD. Assistant Professor, Design Dept., Politecnico di Milano, Italy

Disciplinary Area: Fashion Design

Context: Research + practice; Academic Research

Research: SmartJ. for Barakà

In brief: The partnership concerned the creation of connected quantified-self bracelets for Barakà. This Italian company caters to a male audience based on jewellery references by applying a co-creation methodology between the fashion designer and the engineer's technology. The research included in four phases: brand study, encompassing formal and material aspects, product type and target audience hallmarks; market analysis and potential competitors; identification of existing technologies that could be combined with jewellery; development of a collection that includes scenarios for business as well for leisure. This research presents an example of collaboration between academia and an industrial partner.

Case Study 6. Interviewee: MSc Gabriele Diamanti, co-founder of ddpstudio

Disciplinary Area: Design

Context: Practice

Research: Hannes a multi-jointed prosthesic hand

In brief: Hannes is a prosthetic hand developed as part of a collaboration between the Prosthetic Center of INAIL and the Italian Institute of Technology. It's a new concept of a poly-articulated hand, able to restore over 90% of lost functionality in people with a limb amputation. One of the main aspects of innovation regarding

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

competitors is the achievement of naturalness of forms, movements, and orientation of the rotation axes and hand postures. The thorough study of the anthropometry of the actual hand has guided the prosthetic hand design, from the aesthetics to the mechanical and structural features, allowing the user to perceive the prosthesis not like an external instrument but as an integral part of the body. Hannes received the Compasso d'oro Award in 2020.

Case Study 7. Interviewee: Olga Noronha, PhD., visiting lecturer at Royal College of Arts and Central Saint Martins. Artist based in Portugal and UK.

Disciplinary Area: Jewellery design, art, and science

Context: Practice and Research + Practice

Research: "Medically prescribed Jewellery //'Becoming The Body': An Investigation Into The Possibilities And Affordances Of 'Medical Jewellery'"

In brief: This doctoral research investigated the social and psychological aspects of body modification and medical interventions on and in the body by analysing biomedical research into the repair of the body, surgical procedures, material compatibility, and prosthetic design. The researcher outlined the theoretical underpinnings of the work, the necessary practic-material considerations in producing 'viable' medical jewellery, and the understanding of its reception in different contexts (medical and jewellery). The researcher made many prototypes that were materialising ideas and proposed them as possible futures. This way, she feedbacks from different publics and how it moves through and across other epistemic constructs (art and science). The research sought to minimise or deflect the negative effect of medical repair by developing new speculative designs made of aestheticised scientific technology and medical knowledge. These were used to investigate how they would be emotionally and physically experienced and what knowledge they would gather and convey. This study is an example of academic research.

Case Study 8. Interviewee: Tom Jenkins, Assistant Professor, IxD Lab IT University of Copenhagen

Disciplinary Area: Interaction Design

Context: Academic Research

Research: "Cohousing IoT"

In brief: Cohousing IoT uses research through design to both alternative probe modes of living and prototype speculative domestic Internet of Things devices. These prototype technologies are informed by a public design process that works in two ways. First, it imagines alternatives to existing arrangements of things and devices in the home; second, it produces prototypes that argue for new roles for internet-connected things that both support and sustain the social life of a cohousing community. This study is an example of academic research.

Case Study 9. Interviewee: Camilo Ayala-García, Assistant Professor, Universidad de los Andes, Colombia at the time of the interview, now Researcher at Free University of Bozen-Bolzano.

Disciplinary Area: Materials for Design

Context: Product Design Research + practice Academic Research

Research: CornStalk DIY-Material for Social Innovation

In brief: Do-it-yourself (DIY) materials are an emerging field that has progressively gained attention because of its democratizing power and business potential. In this work, using cornstalk-based DIY materials to foster social innovation among Colombian small farmers is explored. This approach promotes a rural development that respects farmers' traditional practices and beliefs oriented towards collective progress and nature preservation. Hence, the theoretical review regarding social innovation, circular economy, DIY practices, and materials is tested by proving that corn stalk can be used as a raw material to make materials without the need for scientific knowledge, sophisticated technology, and polluting elements. In a second step, the theory and hypothesis were verified by interviewing Colombian farmers with whom the idea of using agricultural leftovers to produce DIY materials was shared and discussed during several workshops. This study is an example of academic research involving a local community for which the innovation was intended.

3.1.3 Analysing the case studies: an interactive tool

During the making of the interviews and case studies, we started to realize that the research and prototype's characteristics are related. For instance, the research's context and general aim might determine the prototypes' nature (virtual, digital, physical, etc.) or the specific aim for which they are made (assess, provoke, communicate, etc.). Still, we could not immediately find common rules that would define such relations. So, we decided to show those connections and see what they looked like. We developed a visual tool that would help us discover the relationships whose existence we could only suppose. Clearly, we were ready to find out that there were no recurring relations and rules.

3.1.3.1 Defining the research area

The purpose of this step of our study was to make evident relationships that we detected by reading and discussing the findings from the previous research steps. We imagined a visual area to place the case studies and point out the connections to all the categorization criteria (aims, discipline, terminology, context, fidelity, phase of process) we used in the literature review (Sect.1.1.2).

The area would represent the characteristics of research in which case studies took place. So, first of all, we had to identify those characteristics.

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

Among the categorization criteria, we knew that the variants of the research that frame the role of the prototype are:

- The "context" and "disciplinary area" in which the researcher works.
- The "phase of the process" in which the prototype applies.

Furthermore, we realised that some critical input regarding the characteristics of the research area also came from the Grounded Theory study. In fact, among the four theoretical concepts, we thought the Concept "Transition" expressed some vital aspects to consider about the research features that frame the role of prototypes.

In Chap. 1, we said that the whole field of design research intended and employed prototypes to make ideas manifest, moving from *vagueness to clearness*. The way such representation is understood and achieved varies depending on the research areas, generating opposite poles: *speculative* and *intangible* on the one hand, *material* and *realistic* on the other (see Sect. 1.2.4.1). In the light of this reading, we emphasised that the research area could be defined as "speculative vs. realistic" and "tangible vs. intangible."

We defined "speculative" as the research that, as a general aim, poses open and reflective questions, elicits discussion, or prefigures possible futures, and supports the making of theoretical knowledge. For instance, we assumed a doctoral thesis would fall in this area.

Quite the opposite, some research's general aim is straightforward to develop and apply a new design solution, possibly right at the end of the research and development process, with not much time and resources dedicated to reflecting and sharing the results (both in terms of practical outcome and new knowledge). We assumed this is the case of research in R&D departments or design consultancy and, partially, in academic research developed with external partners. We called this research area "realistic" and later changed it to "concrete," trying to highlight the nature of the general aim of the research. Indeed "realistic" seemed as opposed to "fictional," which was not what we meant.

Regarding the feature of being "tangible vs. intangible," we referred to the "object" of the research. So, if the research were about, for instance, the making of a new physical product or new material, it would be "tangible." In contrast, if the research were, for example, about a service, the object would be "intangible." We later change "object" into "essence" because the first implied an idea of materiality that we did not want to suggest. We knew that design research could focus on both qualities. For instance, a service might include the use of objects (i.e., a bike sharing service), or a device might imply interaction with Apps and other features that are more digital than physical (more software than hardware). In this perspective, research on interaction and experience design, where both physical and digital objects are applied, would cover both definitions. In our area, they would appear in between the definitions.

Ultimately, we decided to use the definition "speculative vs. concrete" and "tangible vs. intangible" to draw our ideal space to place the case studies. We thought this set of research characteristics could describe all case studies. In contrast, the

context and phase of the research would be lateral information since we felt they were less relevant.

3.1.3.2 Defining the prototype's characteristics

For our visualisation, we had to highlight the prototype's characteristics that we wanted to emphasize. Again we selected them from the categorization criteria. The features that defined a prototype were "Aims" and "Fidelity." Most of all, we wanted to highlight the Aims because we understood that they are the most relevant feature that defines prototypes. While fidelity is not even cited or shared among the design community.

Furthermore, we recalled that - at a very general level, the role of prototypes in design research is to support the production of specific knowledge "about the prototype" and, possibly, to support the production of general knowledge that goes "beyond the prototype" itself. We planned to visualize this feature in our representation.

From making the case studies, we realized that it was helpful to detect also the "Nature" of the prototype. We distinguished three main possibilities.

First, the prototype is "Physical" when it can be experienced directly with one sense - typically sight and touch - and the other senses. We identify "physical" any tangible aesthetic and functional models, regardless of the level of fidelity, and any probs that imply a physical real (not virtual) interaction. Visual aids, such as paper prototypes, would fall into this definition too.

Secondly, the prototype can be "Digital" when it is a software part of the design (i.e., an interface) or it is a visual aid (based on digital technology), such as a video that shows a scenario or tells a story.

Thirdly, the prototype can be a virtual model tested in a virtual environment (that can be or not be immersive). Thus, we pointed out this feature "virtual environment" to point out that these virtual prototypes and environments enable a virtual experience that all stakeholders of the design process can use.

We noticed that in one research, prototypes of different "Nature" are present since they enable to reach different specific aims. Also, one single prototype can be physical and digital, i.e., a smart product with an App to use for interaction. At the same time, both a physical and digital solution can be experienced in a virtual environment. So, the option among "physical," "digital," and "virtual env." is not exclusive.

Furthermore, we realized that in some specific research, prototypes are "fictional" as they represent something imaginary and pretend to be something else or something that might not even be possible nowadays. So, these prototypes do not embody something realistic yet. We called this nature "fictional" and pointed out that it can apply to the other three.

Regarding the categorization criteria "terminology" and "disciplinary area", we thought to keep this variable aside and check if we should integrate them later.

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

We developed a first rough paper model (Fig. 2.1) of the visual tool with all the variables of research and prototype characteristics.

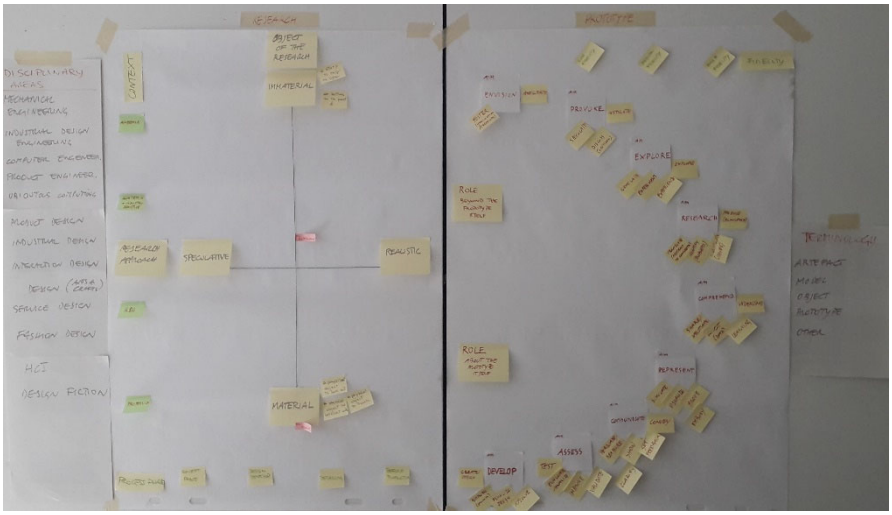

Fig. 3.1 First paper model of the concept of visual tool

We tested this first version with some examples from the literature review. We understood that even if it was promising, using all variables together was ineffective. Therefore, we simplified the concept and developed a digital interactive version of the tool. We thought an interactive tool would better support the visualisation of the relationships we were seeking.

3.1.3.3 Interactive Visual Tool 0.1

From the beginning, we decided that:

- The tool aimed to visualise possible relations between the research and prototype characteristics.
- The tool did not measure any feature or generate quantitative data.
- The tool was designed to support our understating of the phenomenon and elicit discussion with others.

We foresaw that, eventually, together with the first part research, the tool would let us define a general overview of the matter.

So, we transformed the first paper model into a digital version of it. Later we reflected on the fact that even this study, which is purely theoretical, took advantage of the transition from abstractness to concreteness through prototypes (see Chap. 6).

First, we designed a cartesian area (inside the orange square called “research”) where the X-axis identifies the “essence” of the research from “tangible” to “intangible”; the Y-axis identifies the “general aim of the research.” In this area, we placed a dot representing each Case Study.

The list of Case Studies is on the left side of this area. In the interactive tool, a sheet appeared when clicking on any of them. The sheet contained primary data about the Case Study (researchers, a short description of the research and its prototypes, disciplinary area, specific aims, and possibly an image). Also, every Case Study referred to a dot in the central research area. In this visualization a dot represented one research, and all the prototypes made and used within such research. The placement in one of the quadrants of the central area was qualitative. It indicated how “speculative vs. concrete” was the general purpose of the research and how “tangible vs. intangible” was the essence of the research.

To simplify, we decided to overlook the concept of “Phase of the Process” since, from the interviews, we realized that we could not find a process (and a finite number of phases) that was common to all research. Indeed, our first definition of four phases (conceptualization, design development, detailing, before production) worked well to refer to an “industrial product development process” with a quite standardized definition but was not proper for design research in general. So, we overlooked it also because not all authors mentioned it in the literature review.

In the tool, the characteristics of the prototype (aims, role, and nature) appeared around the central area in the larger grey square called “prototype.”

To simplify, we decided to overlook also the concept of “Fidelity” since the design community does not equally adopt it.

The color defined the role of the prototype, from grey (about the prototype) to orange (beyond the prototype).

Each Case Study was connected to the prototype's aims, role, and nature in the interactive tool. So that it was possible to select one Aim (i.e. “Assess”) and find out which dot appeared in the central area. This way, we could see which research/dot had prototypes made to “Assess.” Also, it was possible to select other features, such as the prototype nature (i.e. “Virtual”), and discover which research used virtual prototypes.

In a general meeting, we used this tool version (Fig. 2.2) to check its validity. We discussed the first findings and then proposed some changes.

Some interesting relations were visible: the role of the prototype is “about the prototype” in “concrete” research, and it is “beyond the prototype” in “speculative” research. It was an assumption we already had in mind and confirmed by the visualization (grey dots are on the bottom).

On the contrary, we supposed that research developed outside academia would be all in the lower quadrant and vice versa, but that is not the case. Indeed, Case Study 3 - a design fiction example by a design consultancy - appeared in the area's top (speculative) part.

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

All doctoral theses were on the top quadrant since they all had open questions and led to speculation, even when the object of investigation was very material. Yet, even research for a company, such as Case Study 1, appears in the top quadrants because it develops a fictional scenario to let the partner imagine what design solutions they could apply in their future.

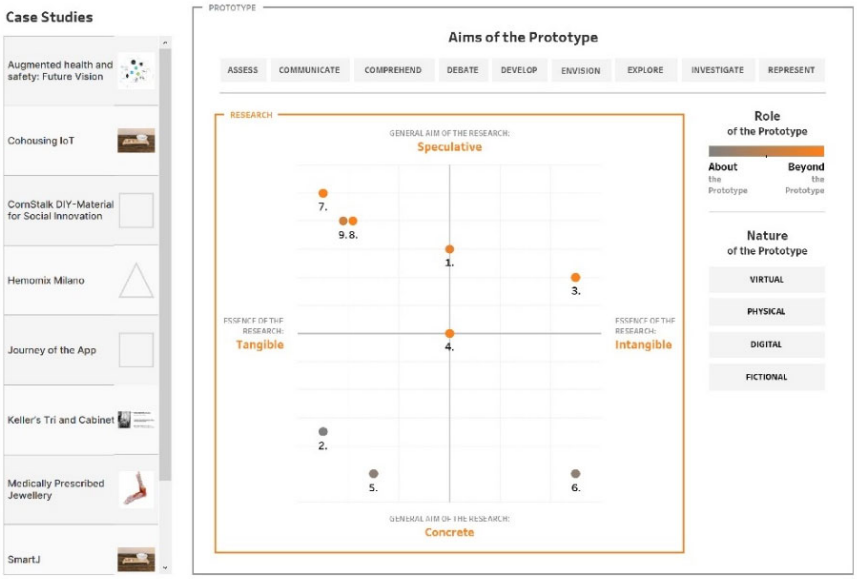

Fig.3.2 First version of the interactive visual tool

The tool appeared interesting but with two significant weaknesses.

On the one hand, the selection of aims was not very effective because most of the Case Studies connected to most aims. So, the choice of one variable on the tool did not generate interesting visible connections.

We realised that this problem happened because we used the first level of aims (i.e., "assess"), not the second ("assess" contains: "evaluate, validate, improve"); also (see Sect. 1.3.1), we did not put any limit on the option of the aims; finally, for each case study/dot we combined the aims altogether.

On the other hand, we realized that placing all research prototypes together was an oversimplification. One dot would not represent the complexity of a research process where different prototypes are made and used for different aims in different moments.

We, therefore, decided to modify the tool.

3.1.3.4 Interactive Visual Tool 0.2

In the new version of the tool, we wanted to highlight the presence of different prototypes for different aims within the same research. For example, a researcher may apply a simple paper prototype for the first conceptual phase, a physical model for the second phase, and a virtual prototype for the last step.

Therefore, we asked the interviewees if the prototypes used in their case study may cluster in groups based on their roles in the research. We let them define the number of groups based on the specific aims they were made for. Thus, we asked to assign to each group one single specific aim. Finally, we asked to place them in the quadrant and define their nature - this way, each case study could be represented by a set of dots scattered in the research area. After a review of them, we realized that a few of them were still represented by a single dot. This case happened when prototypes in such a case study belonged only to one phase/aim.

We identify each case study with a number corresponding to one colour for better visual clarity.

Also, we introduced the information of the "context" in which the research took place as we realized it was an interesting factor to detect. We refined the definition, though, so the option ("Practice," "Practice + Research," "Research + Practice" to "Academia," as defined in Sect. 1.1.2) referred now to the context in which the research took place. So far, it represented the context in which the interviewee worked at the time of the interview, but this condition could have changed in the meantime. So, for interviewees who said they worked across two definitions, we picked the best representation of where the research developed. To make it easy to detect such information, we made different shaped icons instead of just dots (see the box "Context of research" in Fig. 2.3)

Finally, we decided to overlook the identifications of the role of the prototype "about" or "beyond" the prototype itself. Indeed, the first tool's version already proved our assumption, which was less interesting to get the overall picture.

This version of the tool proved to be more efficient in representing the complexity of the research and the role of prototypes. The selection among aims and groups of prototypes was more effective.

Eventually, after collecting the first nine case studies, we added two extra ones to check the appropriateness of the tool with research developed by us. We wanted to test the tool with case studies we knew in detail. We added:

- Case Study 10 The research "artificial intelligence in design" ongoing research about how to integrate AI in the creative phase of the product design process.
- Case Study 11 The study of this book "Paride. Advance prototypes for design research".

These extra examples helped to integrate the overview but, of course, did not cover all possible kinds of research in design. Of course, it could be possible to integrate it further to confirm the first reading or discover new relations. The readers may

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

visit the website https://www.farbparide.dipartimentodesign.polimi.it/ and try the tool by themselves.

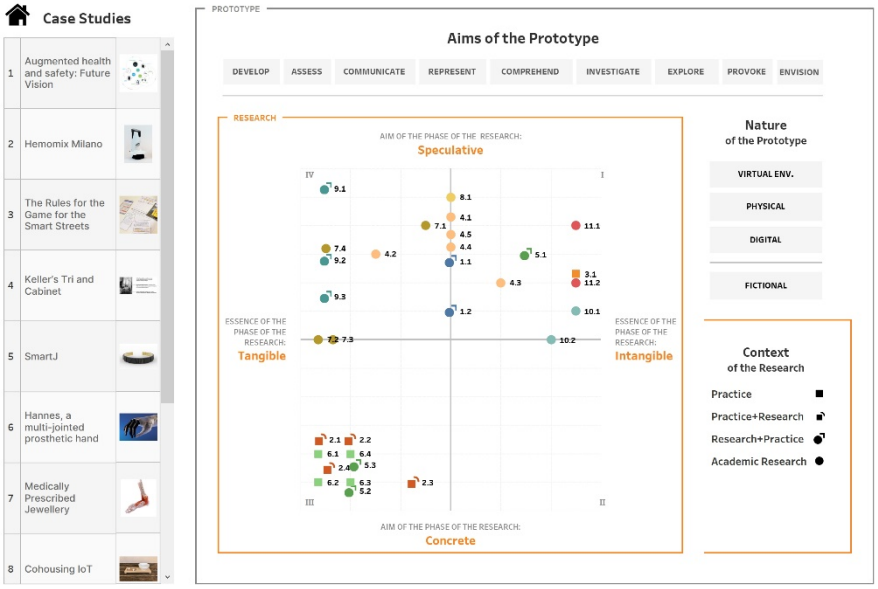

Fig. 3.3 Second and final version of the interactive visual tool

3.2 Visualising relationships

While using the interactive tool, it was necessary to remember that:

- It is a *discussion* tool made to observe phenomena and elicit further debate. The assignment of a place in the quadrant was relative. Thus, the tool was not made for measurements or gathering quantitative data.
- It visualized only prototypes' features concerning the research they are made for. It did not represent the whole research process. Any research phase that did not use a prototype would not appear in the tool.

So, we looked at the Case Studies' visualisation and realised some phenomena.

3.2.1 Reading the whole picture

First of all, Quadrant II, "intangible-concrete," is empty. We realized this has to do with the group of research's interests and contacts, mainly about product design, design interaction, materials, design engineering, and fashion design.

Indeed, the tool was designed after the literature review findings, which covered any design research area. Thus, the tool could enclose case studies from any field, while we collected examples only from our specific areas. Should we want to fill quadrant II, we should ask some communication design experts to participate in the study.

Secondly, we noticed that the academic research (rounded dots) was placed mainly in the speculative area (top two quadrants). In contrast, the research developed in consultancy firms/design practices was more likely to be in the lower quadrants.

This distribution seemed to be coherent with the assumption we had.

Indeed, we read that – traditionally – the prototype is intended as part of a product development process typical of the industry. It supports the progress in making the solution real (concrete research). On the contrary, design research evolved towards more explorative, speculative, and experimental kinds of studies. We described this "academisation" phenomenon (see theoretical concepts in Sect. 1.2.4.1).

Nevertheless, we found exceptions to this simplistic dichotomy, as follows.

For instance, Case Study 3 is about the design consultancy Design Friction, "a design practice producing speculative and critical scenarios for the upcoming presents," as they claim. Thus, it is a design practice that develops purely speculative research. In this Case Study, the prototype supported the making of fictional experiences for the citizens involved in the project of future smart urban solutions. The firm's client was the city of Nantes. Thus, we had a squared icon in the speculative area of design research (Quadrant I).

Then, we have case studies made in the academic context in collaboration with industrial partners. In Case Study 5, the research team developed new concepts of smart bracelets for a fashion company. The research team made a first phase of the speculative research to explore possible scenarios and then set the final designs. In this case, the first group of prototypes supported the vision of alternative design opportunities, while the latter supported the progress toward concrete outcomes. So, maybe, this example well represents what a company seeks in academic collaboration. Indeed, Case Study 1 illustrates an example where the industrial partner

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

entrusted the academic team with developing a whole vision for their future development in a specific area (health and safety). The aim of the research was fictional and explorative, even if it was for an industrial partner. The extensive making of different prototypes embodied that vision, both supporting the development of the design concepts and the communication to the partner. Indeed, we were told that the level of the partner's involvement in the future vision was crucial to the success of the collaboration. In this case, this reflection came from the sharing of data at the time of the interview. We should notice that the study successfully developed further later.

Yet, Case Study 6 represents the most unexpected example, a small design practice, DDP studio, that participated in a comprehensive study in collaboration with two large partners, the Italian Institute of Technology and INAIL (Istituto Nazionale per l'assicurazione Contro gli Infortuni sul Lavoro). In this case, the design team helped the engineers translate the user's needs (people needing prosthetic hands) into design requirements and solutions. They played an essential role in defending the value of form, an aesthetic feature usually overlooked in prosthetic design favoring functionality. Through making many prototypes, design and engineering aspects integrated into an innovative award-winner product.

Case Studies 4, 8, and 9 present the making and application of prototypes to develop advancements in design research.

Case Study 4 is an emblematic example of Research Through Design (RtD). In this Doctoral thesis, the main research questions were about how designers used collections of visual material for inspiration and how new media tools could help the designer interact with such collections. The research was developed by making working prototypes and letting users experience them. The making of the prototype was essential to investigate the research questions.

Similarly, Case Study 8 is an example of RtD. Actually, the whole project is about prototyping. The prototype was used explicitly as a transition (from abstract to concrete) to make people understand the design concepts (social Internet of Things for cohousing Communities). The users' involvement was fundamental to gathering feedback and forming new knowledge about the future application of the new solutions embodied by the prototypes.

In Case Study 9, prototypes were realized to create new materials and show participants in the research workshop that they could make new materials by themselves. Even though the research is about something very tangible and made through physical prototypes, the research questions and findings are speculative as they regard the exploration of using cornstalk-based DIY materials to foster social innovation among Colombian small farmers.

So, this overview shows a manifold of cases that distribute and cover the quadrants in many possible crossing combinations. The exciting aspect is the variety of design research in which prototypes play a crucial role.

It was also interesting to notice the mix of applications, for instance, research of tangible things tested with digital and virtual prototypes and vice versa.

This case entailed two possibilities.

First, products might be embedded with digital technologies that need testing through specific interactive features of the prototype. For example, Heromix in Case Study 2 was developed with several models and prototypes: some simple physical models and some working prototypes that featured the interface interaction. Also, the product was presented to the client in a virtual environment. So, all kinds of "nature" of the prototypes were applied to this kind of industrial product. (see Chap. 6 for further discussion).

Secondly, we collected under the name "prototypes" any item used during the research "to make the idea come true". Therefore, we included videos, scenarios, storyboards, and any other representation support that is mainly visual. If a case study included any such items in a digital version, it would appear in our results under the prototype's definition of the "digital nature." Nine case studies out of ten had digital prototypes of one of these types. This reading meant - we reckoned – that the use of any kind of digital support is commonly part of the design research process.

Lastly, we noticed that it also happened that intangible research objects, such as in Case Study 3 (a fictional experience) and Case Study 10 (an AI-based design tool), are developed with physical prototypes. These cases proved that the physicality of the prototype could be an excellent quality to reach the study's purpose. Either because the physical model could easily involve the stakeholders (Case Study 3); or because sometimes making simple paper prototypes is less time-consuming than making any digital ones.

Then, while all fictional prototypes appear in the speculative top quadrants, the virtual environment prototypes spread in all quadrants. Interestingly, they were all very close to the central vertical line (between tangible and intangible). We interpreted this distribution thinking that they let us experience the interaction, quality of the essence of the research that we would place between tangible and intangible.

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

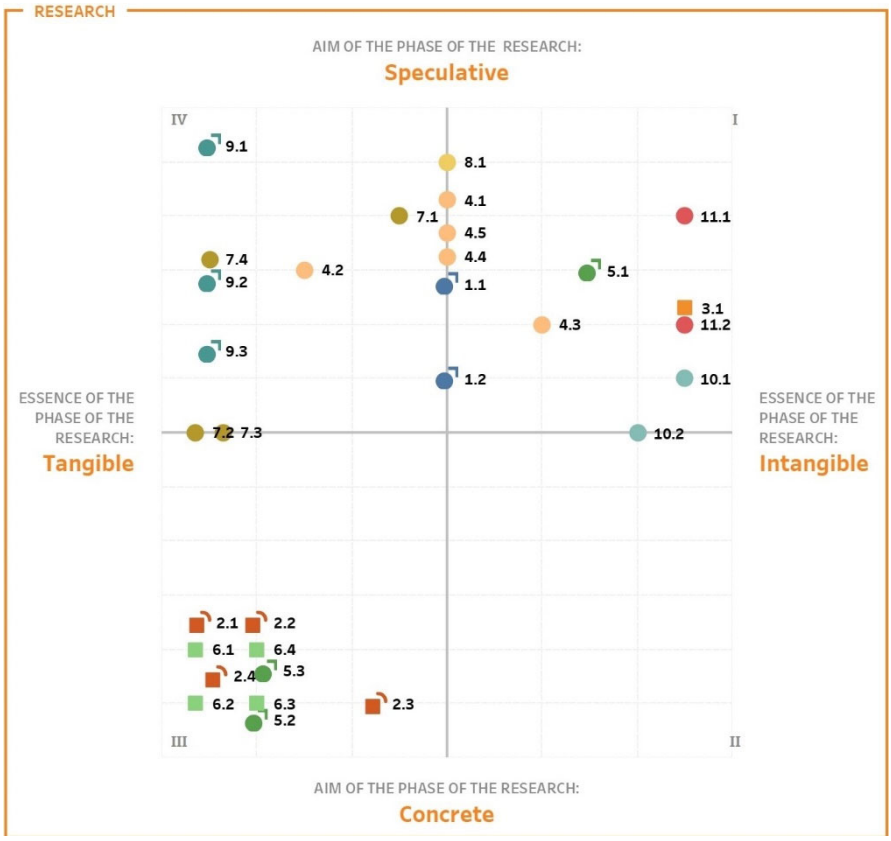

Fig. 3.4 Distribution of Case Studies in the research area of the interactive tool

3.2.2 Reading selected relationships

We made the tool to visualise relationships. The first reading was of the still image altogether. Yet, the interesting extra connection could be seen by using the interactive selection that the tool supported.

As a first step, we checked the relationships between the Aims and the other information. We selected the Aims one by one and observed.

We discovered that most of the dots (16/27) belonged to the first three aims (Develop, Assess and Communicate). Thus, the prototypes made to “develop” and “Communicate” are in different case studies, regardless of the research's context, aim, and essence.

While “Assess” appeared only in the upper quadrants. Possibly for these studies, the researchers wanted to highlight the presence of an evaluation phase that, apparently, is particularly relevant for such speculative studies.

At this point, it was vital to notice that the Aims “Comprehend” and “Provoke” were unrelated to any dot/case study.

So, while our literature review and Grounded Theory study revealed these two aims for the prototypes in design research, they appeared overlooked by the researchers during the making of the case studies. Remember that if it did not appear in the tool, it only means that none of these Case Studies had a phase/group of prototypes explicitly made for comprehending and provoking.

As regards the Aim of “Comprehend”, we found out that one of the roles that prototypes play is to let the researcher understand the matter at hand, collect data and learn from the application of the prototype. Possibly in the researcher’s interpretation, this Aim was enclosed with other Aims. For instance, when prototypes are used to Develop and Represent, many lessons are learned in the process.

Similarly, the Aim of “Provoke” could be associated with the Aims of “Investigate”,” Explore”, and “Envision” as they all support discussion and speculation.

Furthermore, the Aims Investigate and Envision appear only in Quadrants IV and I, confirming that such intents apply more likely to theoretical research. While Aim Explore is also in the III Quadrant, showing that experimentation through prototypes applies to speculative and concrete research.

3.2.3 Highlighting the trends

After observing all possible relationships and reporting the most interesting ones, we wanted to highlight the sequence of dots belonging to each Case Study. It appeared that they could have sequential phases worth investigating. Therefore, after the interactive use of the tool, we connected the dots of each case study to show the trends, as in Fig. 3.3.

We observed that there is not one trend equal for all Case Studies. Indeed, three (n. 1, 9, 11) present a descending trend that shows a movement from speculation to concreteness, maintaining the same quality of essence (tangible/intangible). Case Studies 4 and 6 present a counter-clockwise circle of dots.

Case Study 4 represented a process where the prototypes supported a speculative start (4.1), towards development (4.2) and assess phases (4.3) where the project enters a more concrete realm, to end back into a reflective phase (4.4). The same progression happens in Case Study 6 but all in Quadrant III since the research was *concrete* in all phases.

In Quadrant III, Case Study 2 presents a clockwise circle of dots. The dots following the first one, move on the quadrant and come back to the starting alignment to the vertical line while they descend in the horizontal line. It seemed that these

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

prototypes helped diverge from the starting questions and reached more concreteness.

Also, Case Study 5 and 7 move down towards concreteness and from right to left toward more tangibility, but both come back up for reflection in different quadrants.

Only Case Study 3 and 8 have only one dot, meaning that all prototypes used in these studies share the same main aim.

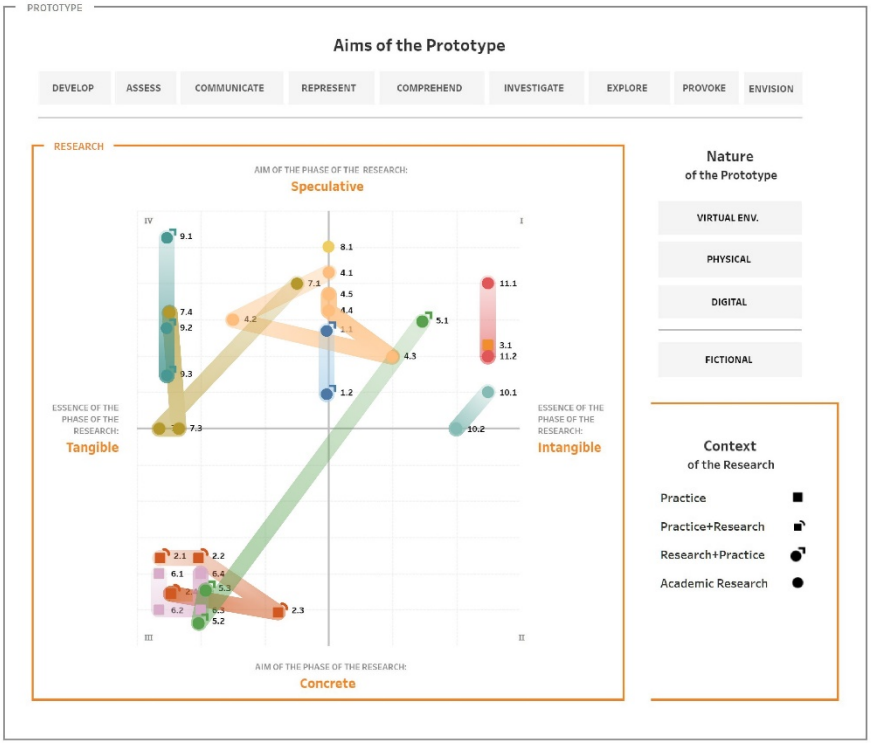

Fig. 3.5 Trends of research phases using different prototypes for specific aims

3.3 Discussion

The tool appears to be useful for reflection on one's research, as we discussed in our team, and to debate with other researchers. Overall, we noticed some themes emerging from using the interactive tool.

3.3.1 About the phases and trends of the research

We realized that different prototypes are developed for different aims in progressing phases of the research. These trends could go toward concreteness or speculation and move from more tangible or intangible parts of the research's object. There was no common trend or strict analogies of similar Case Studies, even though most of them presented a descending movement, which confirms that the prototypes role is to make ideas more concrete. The ascending final dots (those in an upper position at the end of the trend) aim to represent the final design or extend and assess the research both towards theoretical findings or actual development.

While we observed the trends, we realized that the groups of prototypes did not represent all the phases of one research. Thus, a preliminary part of research without a prototype (i.e., a benchmark or state-of-the-art) would not appear in the visualization. Similarly, a final theoretical reflection phase, with no prototype, was not present in the tool.

So, it was essential to highlight that the role of prototypes in design research might also be relative to just a part of it, not to the whole study.

We also realised that, while in an industrial production process the development phases are quite standard, there was not such a consolidated reference in design research. Thus, the definition of phases is entirely relative to each investigation.

Discussing the findings, we also realized that it was essential to consider the research level of development. Some of the Case Studies were about research that developed further or became part of larger studies. So, the role prototypes might play in the first research might continue and evolve later, in other studies. For instance, Case Study 5 became part of a doctoral thesis, and thus, in that context, it contributed to developing a speculation phase that is not pointed out here.

Similarly, for the Case Studies that do not end with a reflective phase, we thought that it could also mean that the theoretical knowledge did not develop together with the ongoing research but might have followed later or been developed by others. In Case Study 6, the designers did not dedicate time to generate theoretical knowledge from their results or formalize them into publications. In contrast, the engineers researching with them elaborated and shared their findings from their point of view.

3.1.2 About the overview

After making and using the interactive tool, we realized that we expected to collect examples of case studies conducted with a "Research through Design" approach and conducted in academic contexts to fall into the top quadrants (the "speculative" area of the scheme), and that was confirmed (see Case Study 4 and 8). Also, we

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it

expected to collect examples of case studies conducted with a "Research for Design" approach in practice-based contexts to be in the bottom part (the "concrete" part of the scheme). And that is confirmed by Case Study 2 and 6.

However, what was interesting to observe the exceptions. Case study 3 was made by a design consultancy for a town council with a design fiction approach (top quadrant). Case study 5 was a study made in an academy for an industrial partner that crosses from top to bottom quadrants. Case Study 1 was made in an academic context for an extra-academic industrial partner, but it pertains to the speculative area, possibly because of its fictional approach. Case Study 10, the study of this book, is a "research about design" and falls into the top quadrant. It is interesting that even such a theoretical work was developed through making a tool that required prototypes that definitely contributed to our *understanding* of the issue and to the development of the final reading.

Eventually, we can say that the role of prototypes in design research varies according to the context in which the study takes place and the general aim and object of the research.

One research might require prototypes of different natures (physical, digital, etc.) that are developed to achieve specific aims (develop, assess, communicate, etc.) in a different investigation phase. Even if research in the academy is more commonly speculative and research in a practice-based context is concrete, nowadays, design may cross such boundaries, as speculative and fictional approaches are helpful also for practice-oriented (concrete) research.

To conclude, we reviewed the literature and analysed it with two approaches. We applied the Grounded Theory Methodology to develop a general understanding of the phenomenon. This approach defined four theoretical concepts that gave us a comprehensive knowledge base to build our research. In the meantime, we gathered and organised information based on some categorization criteria that let define the prototypes. These results gave us a reference framework that we used to develop our study further.

Indeed we mixed these results to make an interactive tool that could visualise the essential relationships that define the prototypes and the studies they are made for. Then. We interviewed experts and collected Case Studies. We placed the case studies in the interactive tool to confirm or discover relationships that frame the role of prototypes in design research.

In Chap. 3, 4, and 5, we report the Case Studies and the discussion raised during the interviews. Further insights developed from the deep investigation.

References

Ayala-Garcia C, Rognoli V, Karana E (2017). Five Kingdoms of DIY Materials for Design. In: *EKSIG 17* - Alive. Active. Adaptive - Experiential Knowledge and Emerging Materials, Rotterdam, 19-20 June 2017

Colombo S, Yihyun L, Casalegno F (2018) Augmented Health and Safety: Exploring Future Scenarios through Design Fiction. In: Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference. Association for Computing Machinery, New York, NY, USA, 363–370. https://doi.org/10.1145/3197768.3201572

Design Friction (n.d.) *The rules of the game for smart streets*. http://design-friction.com/contents/en/#/projects/smart-cities/rules-smart-streets

Jenkins T (2018) Cohousing IoT: Design Prototyping for Community Life. In Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18). Association for Computing Machinery, New York, NY, USA, 667–673. https://doi.org/10.1145/3173225.3173244

Stappers PJ, Visser FS, Keller AI (2014) The role of prototypes and frameworks for structuring explorations by research through design. In: Rodgers P, Yee J (eds) The Routledge Companion to Design Research. Taylor and Francis, pp 163–174

Tenuta, L (2016) Wearable Technologies, the New Era of Fashion. Dissertation, Politecnico di Milano

Fig. 3.1 First paper model of the concept of visual tool
Fig.3.2 First version of the interactive visual tool
Fig. 3.3 Second and final version of the interactive visual tool
Fig. 3.4 Distribution of Case Studies in the research area of the interactive tool
Fig. 3.5 Trends of research phases using different prototypes for specific aims

Silvia D. Ferraris (✉) Francesco Isgrò

Politenico di Milano, Dipartimento di Design

Milan, Italy

e-mail silvia.ferraris@polimi.it