Perspectives on Future Prototyping—Results from an Expert Discussion

Johann Habakuk Israel, Benjamin Bähr and Konrad Exner

Abstract The role of prototyping in today's product development processes has been examined in numerous empirical studies and investigations. In various disciplines, prototyping is understood as a significant methodology for supporting clarification, conception, and design phases. Due to this significance, the question how prototyping will evolve in the future is of high relevance for those who are planning development processes, developing prototyping tools and for design researchers generally. However, quite little is known about possible future evolutions in prototyping and only few authors explicitly address this topic in the literature. This article explores perspectives on future prototyping based on the results of a focus group discussion that was conducted amongst ten prototyping experts from academia and industry. The results suggest that prototyping will maintain and even expand its general importance for product development processes. Moreover, significant changes are expected in the fields of prototyping design methods, prototyping technologies, and societal impacts of prototyping.

J.H. Israel (✉)
Computer Science, Communication and Economy, University of Applied Sciences, Berlin, Germany
e-mail: JohannHabakuk.Israel@htw-berlin.de

B. Bähr
Quality and Usability Lab, Technische Universität Berlin, Berlin, Germany
e-mail: baehr@cs.tu-berlin.de

K. Exner
Industrial Information Technology, Technische Universität Berlin, Berlin, Germany
e-mail: konrad.exner@tu-berlin.de

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1 Introduction: Prototyping Definitions, Processes and Tools

Prototyping is used in various disciplines in academia and industry. Even in everyday life and popular science prototypes are commonly referred to. Nevertheless, the meaning and connotation differ widely, thus describing various characteristics. In many disciplines the term prototyping carries its own meaning and connotation. In product development, prototyping is a means to assure particular product features, e.g. stability or ergonomic functions (Stark et al. 2009), here the prototype should be as precise as possible. During the design process the prototype evolves to become the final product (Kamrani and Nasr 2010). Additionally, the digitization of the engineering design process facilitates the increased application of digital prototypes (Adenauer 2012). Prototyping in human computer interaction describes the process of creating interfaces variants and access their characteristics and qualities while developing the user interface (Pering 2002). The prototype should both be interactive and flexible in order to develop variants on the fly (Buxton 2007). The evaluation of design failures with the customer is the main objective (Lim et al. 2012). In architecture, prototype and final product are basically the same. Because the costs for building a physical one-to-one prototype of a building are high, prototypes that aim at assessing the most important usage features are basically not affordable. However it is possible to asses and verify certain details of the construction, i.e. bent structures, fittings, and material (Gengnagel et al. 2013).

Due to the various perspectives, a common cross-disciplinary definition of prototyping or prototyping processes was not developed yet. Instead, generic descriptions and conceptual frameworks exist. An example by Warfel (2009) which emphasises the duality of prototyping and validating is presented in Fig. 1.

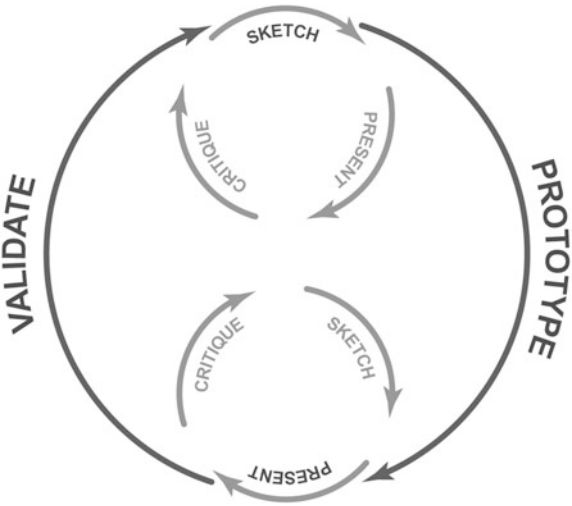

Fig. 1 Prototyping process (Warfel 2009)

Reflecting prototyping from a generic perspective enables discussions between disciplines to occur, but might simplify prototyping in an over-exceedingly manner. Therefore, in addition to the exploitation regarding the discipline specific perspectives on prototyping, further characteristics need to be considered. In an effort to develop a transdisciplinary perspective onto the prototyping process, Exner et al. (2015) conducted a case study among prototyping experts from different disciplines. They investigated multiple dimensions of the prototyping process regarding specific perspectives:

- Objectives (explorative, experimental, evolutionary),
- Dimensions (form, material, concept, principle, process, functions, requirements) and
- Fidelity (high, low, and mixed).

The process model developed by the authors integrates different perspectives from the disciplines, thus providing a basis for a common understanding and encouraging communication amongst design researchers (see Fig. 2), even though neither specific methods nor tools were reflected in the study.

To assess the tools and processes design teams are currently using, McCann (2015) and colleagues conducted a survey amongst 33 designers of interactive products from popular brands, mainly web-based and mobile products. They found that for creating prototype's contents (assets), 50 % of designers are using only one tool, most prominently a 2D digital sketching tool. In order to add interactivity into the prototypes, digital 2D-based frameworks are used to implement high fidelity prototypes, whereas many designers still use standard office tools for low fidelity prototypes. The surprisingly small diversity of tools and the partly insufficient technology suggests that the integration of prototyping technologies and methods

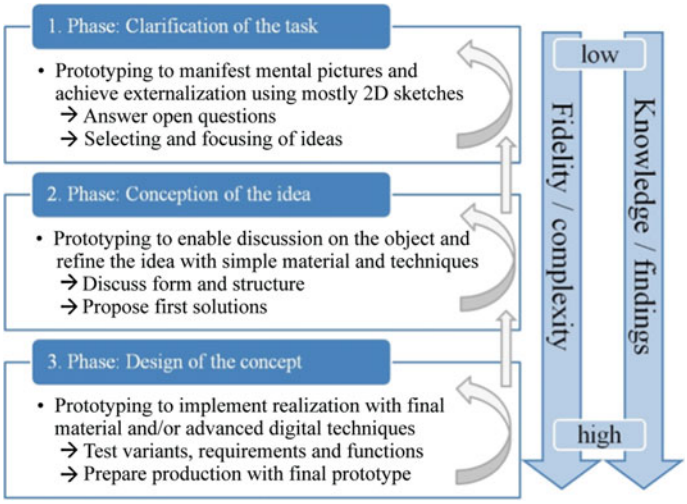

Fig. 2 Prototyping process (Exner et al. 2015)

into the process chain is still underdeveloped. Whether this can be ascribed to technological, conceptual or other reasons is an open research topic that needs to be analysed in future.

2 The Future of Prototyping in the Literature

Only few authors explicitly address the future of prototyping in design and development. Aycan and Lorenzoni (2014) propose live prototyping as a future approach in addition to existing approaches that from their perspective include rapid prototyping, technical prototyping and pilots. Live prototyping "involves releasing still-rough concepts into the context where consumers would eventually encounter them during the course of their daily routines" (Aycan and Lorenzoni 2014). Be it a store shelf or an app store, the prototype has to be encountered by the consumer between all competing choices and distractions. The natural behaviour of the consumer is observed before intercepts and interviews are conducted. The authors suggest that live prototyping conserves capital relative to a full pilot, considers the context, improves forecasting and provides qualitative and quantitative feedback. Aycan and Lorenzoni point out that applying live prototyping has to take cultural norms into account. "While American consumers have shown a hunger to co-create solutions with companies and tend to celebrate brands that embrace experimentation and that are 'permanent beta', this is not always true in global markets. It's important to calibrate what degree of 'roughness' is going to be acceptable based on the market in which you're operating" (Aycan and Lorenzoni 2014).

Some authors, e.g. Hodges et al., emphasise the role of technical prototyping platforms in the future (Hodges et al. 2013). It is supposed that such platforms will speed up the development of prototypes, support the transition between prototypes of various maturity levels and different materials, as well as contribute to the variety of prototyping tools and components (Hodges et al. 2013).

Looking at the future of prototyping, Schrage (2000) stresses the importance of shared spaces for the development of new insights about product ideas and organisations. He suggests that collaborative methods such as serious play will achieve a high share among future prototyping methods.

Blomkvist et al. (2011) emphasise that prototyping has been accepted as a holistic design technique today, but that particular deficits need to be addressed and new prototyping techniques and approaches need to be developed. Based on a literature review, they identified the most critical points with respect to prototyping in the fields of user experiences, contexts, and social interactions. They argue that especially the validity (i.e. the degree of similarity in test and implementation contexts) and the author (i.e. the important perspective of the prototype's author and the user and customer possibilities for participation in the prototypes' creation) need to be investigated in further research. Kora Kimpel introduces another perspective in her contribution "Design Prototyping for planning research and technology development" in this volume. She suggests employing three classes of prototyping

with differing degrees of determination and openness regarding the applications fields and technologies used, namely design prototyping, co-prototyping and participatory prototyping.

In summary, the authors who investigated future directions of prototyping mainly addressed process issues (e.g. live prototyping, serious play), whereas on the technical side, frameworks were suggested for fostering the ease of prototype development. However, the empirical foundations of such works need to be strengthened in order to stimulate the development of new tools, technologies and process models for future prototyping.

3 Focus Group Expert Discussion

Taking the phrase *rethinking prototyping* literally, a qualitative study was performed with the objective to investigate possible roles and technologies of prototyping in the future. The aim of the study was to broaden the view onto this topic and to include external perspectives from academic and industrial experts. Even though a comprehensive depiction of the theme was beyond the scope of this study, the study was set up to discuss the future of prototyping in general, without limitations to particular domains or application areas.

In order to approach the aims of the study, the focus group method was chosen. Focus groups are performed in interactive group sessions among persons from specific target groups. The sessions are led by experienced moderators who ensure the progress of the discussions, but do not introduce their own opinions or positions. Focus groups are efficient methods for qualitative research. They are well established and accepted for gaining insights and information that would be less accessible with other, less interactive methods (Krueger and Casey 2000).

Prior to the focus group expert discussions a semi-structured guideline was developed by involving representatives from all sub-projects of the "Rethinking Prototyping" project. The guideline included open research questions to be addressed in the discussion. All questions were discussed in the preparation team. Critical questions were simulated in mock-up discussions. Finally, only those questions that passed the plausibility check were included in the questionnaire.

Furthermore, stimulus material taken from preliminary results of the sub-projects "Hybrid Prototyping", "Blended Prototyping" and "Beyond Prototyping" (Rethinking-Prototyping 2015) was prepared in form of short presentations, which included pictures and video material. The presentations were held by the moderators and co-moderators to provide impulses to the discussions.

3.1 Subjects

The focus group interview was conducted with ten experts who were selected from the fields of industrial engineering (2 participants), interaction and service design (1 participant), product design (2 participants), and academia with strong records in prototyping research (5 participants). Participants received no compensation for their expenses. Participants included authors of books and conference papers about prototyping, leaders of large third-party funded scientific projects about prototyping and design engineers from globally operating manufacturing companies.

3.2 Procedure

The focus group session was held and protocolled in German. One moderator and two co-moderators led it. The moderator was responsible for the progress of the session. The co-moderator kept an overview and ensured that all topics from the guideline were covered. The second co-moderator protocolled key statements, functions and visions (see Sect. 3.4.2) on flip charts in form of mind maps. The moderator had little influence on the content of the discussion but intervened whenever it was close to losing focus or veering off topic. The session lasted four hours, including a break after two hours. It was videotaped and audio recorded; one co-moderator took a handwritten protocol.

After a short introduction of the moderators and a brief introduction into the aims of the study, participants introduced themselves and explained the role prototyping is playing in their daily life. Each participant had enough time to introduce her or his individual perspectives and experiences. Afterwards, questions related to the topics "functions of prototyping" and "the process of prototyping" were discussed. The stimulus material was then shown and opened up the discussion about "visions", i.e. "new technical possibilities for prototyping" and "the future of prototyping". At the end of the focus group sessions, participants were asked to substantiate their ideas about "future prototyping methods and practices" on cards that were clustered on pin boards.

3.3 Analysis

After the focus group, the written protocols, the content of the flip charts and the cards written by the participants were carefully analysed, aggregated, structured and interpreted and finally discussed among the moderators and another project member in order to form a common perception of the content and answers to the main research questions (Mayring 2003). Thus, the results reflect both the ideas developed during the verbal discussion and the ideas written on the cards.

3.4 Results

3.4.1 Statements

Among the industrial representatives there was no doubt that prototyping is of outstanding importance for their personal work and the development processes in their businesses. All academic representatives shared this opinion and referred to corresponding research results. Some statements included: "We use prototyping from little foam models to large milled or printed products. I find it exciting to think about the diversity of possibilities in it."; "Among all the design activities which we perform, prototyping is a tool which we use every day."; "During the design process with customers we use prototypes to retrieve the current status; this is essential."

Different perspectives regarding prototyping became apparent when the participants described their daily practices. Those differences emerge for example with respect to costs, number and purposes of prototypes: "Prototyping is essential in our company, but it is always stands in tension with the cost-benefit relationship."; "For prototyping we use CAD software, but literally speaking all of our first engines are prototypes as they are produced in small series."; "We distinguish between prototypes which establish a space for ideation and those which can be used to evaluate something or to formulate a particular question."

Shortly after the introduction of the participants, the discussion began departing from economic, tangible advantages of prototyping (i.e. improving productivity, limiting failures etc.) toward the benefits of prototyping for personal and societal development, as well as the dangers of prototyping in supporting the economics of growth: "In the past we built our prototypes with foam. Today we can model them using 3D CAD systems and save a lot of waste."; "The world has gone haywire! What are the aims behind prototyping? Is it technical efficiency? Efficiency causes boredom!".

3.4.2 Categorisation

After categorising the participants' statements regarding the functions of prototyping today, we established five main categories: design and development, external communication, integration of the user, internal communication, and testing and validation. The function categories are listed in Table 1.

The results of the analysis of visions for future prototyping led to three main categories with respect to design methods, technology and society. The visions are listed in Table 2. The categories of both tables are different because the user statements regarding prototyping functions and visions were separately analysed and clustered. The category names are results of the clustering process.

Table 1 List of prototyping functions in today's practice

Category	Function
Design and development	– Clarify questions – Exploration – Materiality – Prototype as abstraction and/or simplification – Reduction of development costs – Reduction of development time – Sharpening the idea and/or the mental model – Variant development by means of virtual prototypes – Visualisation of concepts – Visualisation of ideas – Visualisation of the essentiality and/or the "message" of an object
External communication	– Convincing the marketing, management, and customers – Demonstration, presentation
Integration of the user	– Haptic experience – User experience – Validation of aesthetics
Internal communication	– Competence exchange – Cross-department communication through prototypes – The prototype visualises the internal structure of an enterprise – Integration of competencies of multiple persons or departments – Nonverbal communication through the prototype as physical object
Testing and validation	– Functionality testing – Increasing of the technical efficiency – Proof of effectiveness – Proof of completeness – Robustness/dysfunctions – Validation of requirements

3.5 Discussion

The prototyping functions in practice today (Table 1) as named by the participants are well covered in the literature (cf. Adenauer 2012; Exner et al. 2015; Kohler et al. 2014). They contain no surprising categories or functions. However, the list is comprehensive and emphasises expertise of the participants and their familiarity with the respect to prototyping. Given this, the following list of visions of the future of prototyping (Table 2) can be regarded as substantial.

The visions of the future of prototyping as expressed by the participants have a different and much broader scope than today's function. This can be either due to the fact that we asked the participants closed, fixed questions to describe their daily practices and open questions to express ideas and visions. Furthermore asking for input regarding visions and future-related aspects might have stimulated the participants to think in larger contexts.

A number of trends can be derived from the list of visions of the future of prototyping (see Table 2). First of all, the activity of prototyping will remain an

Table 2 Visions of the future of prototyping

Category	Visions
Design methods	1. Even greater use of prototypes as communication media 2. One-to-one functional representation of complex products and systems (a) Deep cross-module integration of prototyping sub-functions and sub-systems (b) Massive increase of virtual prototypes (c) Prototypes can be used to guarantee the functionality, reliability and informational value of future products 3. Production technologies for products and prototypes are moving closer together (a) Prototypes can go into production by means of prototyping technologies 4. Prototyping of tools (as distinguished from products) will increase 5. The environment will become the laboratory, i.e. prototypes will leave the laboratories location-based services and functions will be developed in situ
Technology	6. Generative prototyping 7. Hybrid prototyping (a) Tools which allow to combine digital and physical prototype elements in order to address all human senses 8. Materiality (a) The materiality of prototypes (i.e. their surface) become modifiable, e.g. from wood to metal to plastics 9. Quick changes between physical and virtual prototypes (a) Testing of physical interaction properties (b) Usage of new and fast rapid prototyping technologies 10. Simulation of human-prototype interaction (a) Possibilities of entirely digital prototyping without the loss of user experience (UX)
Society	11. Critical Design (a) Invocation of societal debates 12. Crowd Prototyping (a) Deployment of not-yet-finished products (beta releases) (b) The unpredictability of the users will become a driver for creative design changes of the product (c) Users/the network integrate it in their daily working and living structures 13. Modular prototyping (a) Prototyping using tested and validated sub-modules 14. New application domains (a) Printing food (b) Printing human organs 15. Open source 16. Prototypes as final products (a) Beyond prototyping 17. Prototyping for fun (the “Lego” principle)

indispensable element of the product development process. Its status is even likely to increase (1) and reach the customer (12, 17). None of the current prototyping functions were explicitly designated or earmarked to become superfluous in the future. However, no new functionalities related to creativity and the ideation process were mentioned, either. This suggests that the general prototyping process

(see, Fig. 1) will not change; however a quantitative change is likely to happen, e.g. in terms of increased usage frequencies.

Furthermore, analogue and low-tech prototyping techniques, i.e. paper prototyping, were not mentioned. Today such techniques are popular because of their easiness, rapid availability, low costs etc. The fact that they were not mentioned suggests that users expect the high-tech prototyping of tomorrow (2, 8, 13) to be as easily available as today's low-tech prototypes.

Specific future technologies, i.e. holographic displays or particular 3D printing techniques, were not specified. However, new application possibilities and prototype features were mentioned, i.e. printing food (14) and modifiable material properties (8), which require new technologies. The fact that the technical realisation of such new possibilities was not mentioned suggests a faith in technology, i.e. that the participants were confident about the general technical progress and that they have a great degree of trust in the developers of prototyping technologies.

Virtuality and virtual prototypes are regarded as central building blocks in future prototyping (2b, 9). Nevertheless, virtuality alone seems not to be the sole solution, as the physical contact with the prototype was regarded as indispensable (7, 8, 9).

The societal impact of prototyping was among the most prominent topics discussed during the study. The participants see prototyping as a means to enable users (citizens) to develop products according to their (and not to the markets) needs (11, 12c, 15). On the other hand methods that involve the user in the value chain were also mentioned and partly critically assessed (12a, 12b).

The convergence of prototypes and products and the "permanent beta" attitude were also addressed by the participants with respect to production technologies (3) and deployment (12, 16). This is possibly the most radical change which can be derived from the study, as it opens up the questions of many industrial product development processes and practices for serious discussion, e.g. milestones, release and start of production dates, marketing strategies and even product lifecycle concepts, as well as personal design approaches, heuristics and strategies.

The fact that many functions of today's prototyping (Table 1) are not listed among the visions of future prototyping (Table 2) should not be read to mean that the participants think that today's functions will play no role in the future. None of the participants provide any comments in this vein; on the contrary, the relevance of prototyping as a central means for development processes in the future was unanimously emphasised.

4 Conclusions

This study was conducted as an attempt at assessing a view of the future of prototyping. The results suggest that changes can be expected in the categories of design methods, technology, and society. The participants of the study showed particular interest and expectations in future design methods. However, they were less concerned about their future technical implementation, which were considered

as more or less given. Furthermore, the societal implications of future prototyping methods and techniques were actively discussed amongst the participants, particularly as they expect the importance and dissemination of prototyping techniques to spread in the future. The dissemination of prototyping in the everyday life of a society can be considered one of the most relevant changes to be expected in the future of prototyping.

Further studies are required to investigate the identified trends in depth, and to reliably predict their societal implications.

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