

What can we learn from outstanding designers? The relationship between design expertise and prototyping

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Abstract

This paper contributes with insights regarding design expertise and prototyping. Seven high performers – Outstanding Designers – were interviewed to learn about their prototyping activities. The Outstanding Designers emphasised prototyping for reflection, gaining certainty, and cooperating with clients. They expressed a strong attachment regarding the use of prototyping that results in specific routines. We call this behaviour the Outstanding Designers' bonding with prototyping. The main insights were synthesised into a model outlining the relation between design expertise and prototyping.

Keywords: outstanding designers, design expertise, prototyping, design practice

1. Introduction

As more serious complex problems of our time need to be solved, more people should be empowered to help solve them. Therefore, increasing efforts are made to embed problem-solving strategies and design activities such as prototyping not only into schools (OECD, 2022) but also into companies and for non-designers (Brown, 2009). Prototyping activities are known to impact the process of complex problem solving. Coherently, a large body of research has been done for contributing to a better understanding of prototyping's impact on the process (Deiningner et al., 2019; Lim et al., 2008; Schrage, 1993; Yang, 2005) and on the designer (Dow et al., 2009; Gerber, 2009; Gerber & Carroll, 2012). Furthermore, little is known about how designers with a high expertise level – the Outstanding Designers (Cross, 1998, 2001, 2002; Cross & Lawson, 2005; Lawson, 1994; Roy, 1993) – are using prototyping.

2. Theoretical concepts

Although high achievers in design are admired for their outstanding design outcomes, little research has been conducted on this group of designers. Most of this research was done more than 20 years ago (Candy & Edmonds, 1996; Cross, 2001, 2002, 2003; Cross & Clayburn Cross, 1996; Lawson, 1994; Roy, 1993b). There are many reasons to investigate Outstanding Designers. Cross and Clayburn Cross (1998) have investigated exceptional and Outstanding Designers and have commented that, 'many studies of designer behaviour have been based on novices (usually students) or, at best, designers of relatively modest talents' (Cross & Clayburn Cross, 1998, p. 141). Hence, Cross and Clayburn Cross object that investigating only 'modest talents' will limit our view of design expertise. Cross argues that 'studying outstanding or exceptional designers may give us different, and more relevant insights and understanding of design expertise' (Dörner et al., 1994, Cross, 2004a, p. 438). Furthermore, Cross and Lawson (2005) claimed relevance to study Outstanding Designers to advance research in order to 'not holding back progress in design methodology'. They argue that not

investigating exceptional or Outstanding Designers would lead ‘to weak or even inappropriate models of design activity’ (Cross & Lawson, 2005, p. 283). Nearly 20 years later researchers still claim a need for to ‘progress knowledge building on key points of the ‘expertise’ in the design profession’, and therefore, suggest more studies of expert designers have to be done (Tollestrup et al., 2023, p. 1244). To sharpen the conditions for data collection to create a better understanding of design expertise at a high level, we focused our investigation on Outstanding Designers and on one specific design activity: prototyping.

We define the term ‘prototyping’ as an activity for creating tangible artefact(s) to visualise an idea or object or part of an object in different degrees of detail. The term ‘prototype’ includes virtual, e.g., CAD, intangible (role play) and physical (mockup) forms. A prototype is often described a three-dimensional (3D) and tangible visualisation of a design idea’ (Jobst, 2023, p. 55). This research was guided by the following research question.

RQ 1: How do Outstanding Designers use prototyping in the design process?

3. Methodological approach

This research aimed to learn from Outstanding Designers. Outstanding people are – as the term describes – rare. In addition, to the small number of Outstanding Designers, it is often difficult to involve them in a study. This behaviour is the reason for few research: ‘Most studies of designer behaviour have been based on novices (e.g., students) or, at best, designers of relatively modest talents’ (Cross, 1998, p. 141). The reason for this approach is obvious – it is easier to recruit such people as subjects for a study. Moreover, Lawson and Cross (Cross & Lawson, 2005) described that designers with high expertise tend to be open only being involved in a single research approach: interviews. Nevertheless, case studies also enable conclusions to be drawn based on a smaller number of participants.

As the topic of Outstanding Designers has been rarely investigated, we decided for an exploratory research approach. Consequently, we applied an explorative approach based on interviews to investigate Outstanding Designers use of prototyping activities. As we aimed also at an explorative approach and as ‘unstructured interviews are more suitable for an exploratory study’ (Blessing & Chakrabarti, 2009, p. 272) we developed a guideline with a list of questions to ensure that the interviews were (to some extent) comparable, and at the same time this approach would be flexible enough to allow for reaction if new topics emerged.

4. Data collection

The data was collected through interviews with seven Outstanding Designers.

Sample

The sample of this study are Outstanding Designers. The term ‘Outstanding Designers’ was coined by Cross (2001), who greatly contributed to the research on design expertise. Cross describes ODs as ‘highly creative or talented individuals who have become successful and highly regarded designers, with international reputations both within and beyond their professional peer groups.’ (Cross, 2004b, pp. 437–438). For identifying designers as sample for this study we built on concepts and descriptions from other researchers in the field of (design) expertise. Based on these concepts we developed six criteria (Criterion 1: Practice; 2: Success; 3: Reputation; 4: USP; 5: Design Focus; 6: Role Model) used as a means for the identification of Outstanding Designers. Designers with diverse backgrounds were selected for the interviews to obtain insights from differently elaborated expertise due to different fields of design.

Professional background of the sample

In Table 1 the interviewees are listed anonymously. The ODs are described by their background in Industrial Design and the focus of their work, which are the reasons for their selection for the interview.

Table 1. Professional background of interviewees

	Discipline	Field of expertise
OD1	Industrial Designer (Male)	Consumer goods
OD2	Furniture Designer (Female)	Furniture and consumer goods
OD3	Product Designer (Female)	Consumer goods
OD4	Fashion Designer (Female)	Furniture
OD5	Industrial Designer (Male)	Furniture
OD6	Industrial Designer (Male)	Consumer goods
OD7	Engineering Designer (Male)	Office furniture

Procedure & Survey Development

In total 15 items were developed for the guideline. The items were developed based on concepts from the research literature (Ehrlenspiel, 1995) and design methodology (Blessing & Chakrabarti, 2009; Pahl et al., 2007).

- 1 Personal Data: In this section, participants were asked about personal data and professional background (example question: educational background).
- 2 Prototyping as Design Activities: Here, the respondents were asked about their perceptions of prototyping, the important functions of prototypes, and typical and core situations for using prototyping (example question: What is prototyping for you?).
- 3 Prototyping in Practice: This question asked the participants about the value of prototyping in their work. They were also asked for a core moment of using prototyping (example question: Is there a moment when you cannot do without prototyping?). If yes, please describe this moment.

Data analysis

The responses to open questions from the interview study were analysed using inductive and deductive coding. The developed coding system consists of three deduced categories regarding activities of prototyping. Each category structures the activities of prototyping related to a different aim. The codes, subcategories and categories and are all theoretical assumptions in alignment with the research literature. The results and insights from the study are presented in the following section.

5. Results

The obtained datasets were rich and offer a good impression of the use of prototyping and their value for Outstanding Designers. In the centre of our research is the designer, in his/her environment with his or her design behaviour and expertise. This obvious fact was taken into account in this research involving prototyping activities which are related to the task (e.g., dealing with ambiguity), person (e.g., emotional attachment towards prototyping), and interaction (e.g., sharing mental models). Therefore, the ODs' answers related to prototyping are structured into person-, interaction- and task-related activities of prototyping. Often one quote addresses more than one activity. This overlap of activities was considered and then structured into the more obvious category. The use of prototyping activities by seven Outstanding Designers was identified through their interview responses. We allocated each participant a label for reasons of anonymity (to feel free to express their perspective). We consecutively numbered the seven Outstanding Designers –with the labels OD1 to OD7– to enable the identification of responses from the same person, (see Table 1). The quotes are designated with a code-ID that consists of the prefix 'OD' for Outstanding Designer, followed by an 'P' for prototyping, and a consecutive number of the quote (e.g., ODPQ3). The respective author of each quote is identified by a label and listed after the quote in parenthesis.

Task-related activity of prototyping

In this part quotes are reported regarding prototyping activities which are related to tasks.

Insight: Being aware of reflection

The cited quote below described awareness for reflection. Three quotes – ODPQ1 to ODPQ3 – expressed that these Outstanding Designers feel supported by their prototyping activity, that allows them to reflect at a deeper level. One Outstanding Designer described reading the ‘questions’ of a prototype. The designer mentioned that a ‘prototype promotes questions’ which speeds up decision-making. Thus, one must be aware of arising questions. However, awareness is needed to read the questions and to identify cues of uncertainty to make full use of the questioning potential of a prototype.

ODPQ1: ‘I build, at least the first 3D sketches [e.g., in plaster], prototypes myself. This is really important that I do it myself. I consider it important to do it myself because from the prototype emerge a lot of questions, which must be answered, and there are permanent decisions to be made. As I want to decide myself, that is why I prefer prototyping myself.’ (OD3)

The designer also expressed an emotional attachment to prototyping and it seemed to be a routine (ODPQ1). In addition, there are indication that question asking that involves verbalisation is applied.

ODPQ2: ‘You have ideas, and then you sketch [or prototype]. Then you reflect on this idea and then you go on. You empty your head by sketching [or prototyping] and you start again, that is the way (...). And this reflection that starts again, to look critically at it and repeat [to sketch/ prototype] again. This is a process with distinct steps. I do quite a lot of steps, yes. I do so! The same is true for prototyping.’ (OD1)

Awareness for the support of (sketching and) prototyping for reflection.

ODPQ3: ‘You need an empty head. You have to sketch or prototype. If not, there will be like a traffic jam in your head.’ (OD1)

Human working memory was described as ‘needle eye of thinking’ (Sachse et al., 2014). The Outstanding Designers’ quote expresses an awareness of using prototyping (and sketching) for facilitating cognitive processes.

Insight: Implementing best practice routines of prototyping

ODPQ4: ‘To hand it [the prototype] out to another workshop takes too long for me, four weeks or so. Then I have already forgotten the question and don't know why we did it now.’ (OD3)

Implementing routines to build prototypes in order to get answers to questions and to facilitate and speed up the continuation of the design process. Prototypes are built to immerse, to reflect and for to gain certainty (ODPQ7).

ODPQ5: [You need to have an own workshop or you] ‘don't have the thread, like that. That's when it breaks off. So, this immersion is obviously interrupted, [and], to some extent, this dynamic is important, yes.’ (OD6)

ODPQ6: ‘It happens often that in the morning we talk about a design idea, and we finish the meeting by agreeing to meet again at lunchtime, each one with his/her prototype. At lunchtime, we present the prototypes to other team members. Our attitude is: demonstrate or die! Meaning: if you want to convince us and the others of your idea, you have to demonstrate it [with something physical].’ (OD7)

A best practice routine to build early, quick, and rough prototypes to transfer information and to attain a shared mental model. Moreover, the routine and ‘ritual’ to use prototyping for cooperating and convincing other team members. Further motif to implement prototyping routines is the use of prototyping to strive for best solution approaches and success (ODPQ6).

Person-related activity of prototyping

Insight: Gaining certainty

ODPQ7: *[To prototype is] 'Like an essence, [there is] a good possibility to get the essence out of a solution. You will condense and wonder is it really necessary? Can we kick it?*

To make it as simple as possible, however, not simpler. This a process which is iterative and requires many, many repetitions, and iterations.' (OD4)

ODPQ8: *'There is something that allows me to sort out well my thoughts. (...) the first is: to go in the model shop to stick things together and to say let's have a look at – what I have reflected before'* (OD7)

OD7 perceived prototyping as essential for reflecting on activities and for gaining certainty. To transfer information is a precondition of receiving feedback on one's own mental model and developing a shared mental model (ODPQ8).

Insight: Allowing ambiguity

ODPQ9: *'Sometimes the prototype is different from what I thought, but I am open to this kind of hazard.'* (OD1)

The search for certainty is a reason to prototype. Nevertheless, there is also awareness of prototyping's benefits to allow ambiguity unexpected discoveries. We assume they were also aware of reflection on a presented prototype because they realised the deviation from the mental model (ODPQ9).

Insight: Striving for success

Prototyping is used to strive for success.

ODPQ10: *[The client:] 'What now? Building a prototype for the pitch? More time? More money? This is not intended!' They accepted it and we won the pitch. This was definitively more convincing than a nice rendering that promises all but does not deliver what it suggests.'* (OD7)

In quote ODPQ10 the designer expressed the use of prototyping to develop a shared mental model and to cooperate with the clients.

ODPQ11: *'This internalised idea, that what I did today will be for sure in doubt tomorrow initially, we do have that approach, and I have it strongly. And I believe this is necessary in order to not be satisfied too early to avoid getting stuck in mediocrity.'* (OD4)

The use of prototyping to strive for success and supporting own high expectations and standards are expressed. In the quote ODPQ11. There is also an awareness of using prototyping for reflection to increase certainty in the quote (ODPQ11).

Insight: Bonding with prototyping

The quote ODPQ12 to ODPQ14 expresses a strong statement and emotional attachment -that we designate as bonding with prototyping.

ODPQ12: *'Prototypes are very important; I do not work without prototypes.'* (OD1)

Prototyping is implemented as routine. Prototypes in 1:1 dimension is considered being supportive for the search for information, for reflection and gaining certainty.

ODPQ13: *'To find out the dimensions. It is for testing it [a prototype of a chair] with the back and the bottom this is the same with the dimensions for finding the proportion and relationship to the body. Therefore, a 1:1 prototype is very important. And therefore, it is better not to make it out of paper but instead to realise it immediately with material. "Where can you feel it?" That allows you to sit and reflect on it.'* (OD2)

ODPQ14: 'Prototyping in our own workshops means we have shortcuts, and we spend less time in comparison to outsourcing the prototyping. We do prototypes on our own. We can get feedback quickly. By doing so, we are deeply involved.' (OD7)

In the Outstanding Designers quotes (ODPQ13; ODPQ14) they describe their attachment with prototyping resulting in routines or establishing a workshop supporting the use of prototyping.

Interaction-related activity of prototyping

The two previous activities related to the goal and the designer as a person. Here, prototyping activities are reported that are used for interaction.

Insight: Cooperating

The affiliation between client OR team/designer is relevant for a positive and constructive working situation. In the answers the use of prototyping for cooperation is stressed.

ODPQ15: '[prototypes] stress the professionalism. It supports and helps the person who will give the money – let's say that he can feel more certain.' (OD4)

In quote ODPQ15 the client's affiliation is relevant for successful cooperation, and the designer displays expertise to strengthen this affiliation.

The interaction 'transfer of information' is relevant for a shared understanding and mental model in a selling or presentation context. The designers use prototyping displaying expertise and transferring certainty to the client (ODPQ15).

ODPQ16: 'We develop the prototype until the very end of the process in order to pass it onto engineers. We want to avoid having to accept "another five more screws" for the chair.' (OD7)

The quote ODPQ16 expresses the use of prototyping for cooperation, to search for information, to transfer information and to develop a shared mental model. In addition, the quote also reported a use of prototyping to master the design, and to gain certainty. Part of using prototyping is striving for success.

ODPQ17: 'Clients have an increasingly bad comprehension of sketches. Fifteen years ago, it was possible for me to present a design and talk about it based on sketches. Nowadays, it is no longer possible: you need at least a rendering or a [high-fidelity] prototype. You can no longer expect that a client has much imaginative power.' (OD3)

The designer's prototype 'fills' the lack of imaginative power of the client. The quote ODPQ17 stated that prototypes are relevant to transfer information and to develop a shared mental model with the client and expressed the intent to cooperate with the client on a prototyping level.

Insight: Attaining a shared mental model

ODPQ18: 'If you want to bring something into the world, people need to see something photo realistic to avoid uncertainties. That is the point. It demands quite an imaginative power to move from a sketch to a finished product.' (OD4)

To create a mental model from a sketch to a product need quite an 'imaginative power'. OD4 was aware that transferring information must support the imaginative power of clients, suppliers, and companies via prototypes. Prototyping is used for to transfer information, to support a shared mental model and for cooperation (ODPQ18)

ODPQ19: [to build rough prototypes in the model shop] 'Like this, it becomes vivid, and by doing so all the team can see what I mean. It becomes tangible. Parts might still be interpreted from another perspective. I think this is the best basis for a discussion.' (OD7)

In this quote the designer uses prototyping and allow ambiguity. In addition, prototypes are built to search for information, to transfer information, and to develop a shared mental model for cooperation and for receiving feedback on the own mental model (ODPQ19).

Summary of prototyping insights

The Outstanding Designers emphasised in their quotes the relevance of prototyping activities in their design process. Especially the relevance of using prototyping for reflection, and hence, an awareness for reflection is expressed. For facilitating their prototyping habits, the Outstanding Designers are implementing best practice routines. This supports not only reflection in a structured but also in a systematic and regular way based on prototypes. Moreover, the Outstanding Designers are entering in a circle of reflection and prototyping and vice versa. Another Outstanding Designers mentioned to align the concept with the prototype in order to develop an ‘interesting’ design. The Outstanding Designers’ approach to reflection seems to be driven by precise analysis, the alignment with the design frame, the concept (and criteria). Reflection is an activity that can support the human need to master a situation. The Outstanding Designers expressed a need to reflect, not only to gain certainty, but also to master the design by prototyping. In the Outstanding Designers answers specific routines were reported to support the prototyping approach through workshops, well-equipped and used by specifically trained staff. Additionally, routines for prototyping were implemented e.g., to pitch ideas within the team (ODPQ4). These mirrors evidence for a strong emotional attachment to prototyping. We designate the strong positive emotional attachment as ‘bonding’ (Lozoff et al., 1977). Bonding is a term that we define as being like a strong parent–child relationship which leads to an optimistic view for future projects. We chose the term because this connection is more emotional than rational and feels intuitively ‘good’ and ‘reliable’.

6. Discussion

The identified prototyping activities were underpinned with the research literature. The main findings regarding Outstanding Designers expertise with prototyping were synthesised into one preliminary and explanatory model. The model was deduced to visualise, discuss, and argue our main assumptions.

6.1. The relation between outstanding designers’ expertise and prototyping

Main findings from the quotes are that the Outstanding Designers are aware of prototyping strengths and can fully explore these. In sum, this leads to an emotional attachment with prototyping. Out of many activities used, the Outstanding Designers highlight some important ones in their answers. The Outstanding Designers emphasised using prototyping to reflect based on prototypes in order to gain certainty based on evidence on an emotional level. Several Outstanding Designers mentioned the use of prototyping to develop and complete their designs to ensure they can master all details of the design. Some Outstanding Designers also mentioned the relevance of storing information in a prototype to support the working memory during the design process (Sachse et al., 2014). Several Outstanding Designers reported using prototyping to reduce complexity and they were aware of using prototypes to gain certainty and to accelerate their decision-making, and to speed up their design process.

For analysing the data an inductive and deductive approach was applied and thus codes based on research literature – such as user centeredness and user tests – are deduced. In the answers the topic of user testing was not addressed by the Outstanding Designers. To implement user tests in the design process is postulated and practised especially in the Design Thinking context and is a key factor for innovation (Kelley, 2005). The Outstanding Designers had great experience and maxims for action, so why did they neglect to use prototypes for user testing? We assume Outstanding Designers consider individual and personal experience as relevant as testing with users. The relevance of personal experiences as a basis for a ‘problem frame’ is postulated by research with Outstanding Designers. Cross reports the case of an Outstanding Designer, who developed a sewing machine. The origins of the new design features were based on experience and some personal use of a sewing machine. Cross identified in his research strategic knowledge of Outstanding Designers who applied three strategies in the early process phase. One of these three strategies is to develop a framing. The Outstanding Designers frame ‘the problem in a distinctive and sometimes rather personal way’ (Cross, 2001a, p. 4). We postulate that Outstanding Designers prefer to build on personal experience rather than on user testing. This approach might become a gateway for limitation of relevant information and to take over only one personal perspective to a problem. Outstanding designers create positive experience with framings based on personal experience. If the design problem is outside the Outstanding Designer’s, we wonder whether

Outstanding Designers question their (past) strategies. Are Outstanding Designers open to taking a risk and trying a new strategy?

We suggest conducting further research on this topic to discover why Outstanding Designers do not use this opportunity to improve their design process. Pursuing this insight further is outside the scope of this thesis and an opportunity for future research. Various Outstanding Designers considered ambiguous prototypes as relevant. Ambiguous prototypes are open to interpretation and can support unexpected discoveries. In the responses was stressed the relevance of prototyping early and throughout the entire design process in an emotional and reliable way ('That is why I prefer prototyping myself'). Some Outstanding Designers reported using specific prototypes (e.g., '3D (plaster) sketches', Q9) and implementing prototyping routines such as sharing prototypes at lunchtime.

Some of the Outstanding Designers described an awareness for minor questions or cues indicating uncertainty that might arise during the prototyping process. We interpret this as one indication for awareness of reflection. These cues for uncertainty can signalise the designer to interrupt and start to reflect on the current situation. Part of Schön's (1992) description of a reflective practice is the designer having a conversation with the preliminary outcome of a design situation. In the reflective practice approach the designer reflects using sketches and prototypes. In the answers there is indication that the Outstanding Designers are aware of using prototyping for reducing complexity. Furthermore, the Outstanding Designers relate cues for uncertainty with reflection activities. We assume the Outstanding Designers own standards, expectations, and criteria to reduce the uncertainty. The Outstanding Designers prototyping approach switches between allowing ambiguity and emphasis on reflection is in line with the research literature. This approach is described as 'ideal' for the concept generation, where concepts are developed based on repeatedly applying a divergent and convergent process. (Cross, 1994; Pugh, 1991). We assume that the Outstanding Designers have a powerful motivation to reflect efficiently because of previous, positive experiences. This insight can relate to research by Dörner (1994) that certainty positively influences the quality of the outcome. In their answers, a strong positive emotion was expressed regarding the use of prototyping. We use the term 'bonding' with prototypes to describe this strong relationship between the Outstanding Designers and their prototyping activities ('I do not work without [them]'; 'demonstrate or die'). One possible advantage of bonding is a form of fixation on this activity that already –in the past– led to a successful outcome. Nevertheless, this approach might lead to reduced openness for other activities such as user involvement. The Outstanding Designers fixation on prototyping might hinder selecting more appropriate activities for improving their design process. The Outstanding Designers' attachment to prototyping and towards their prototypes was evident in their answers and seem to result into a strong source of motivation for using prototyping. The main findings and theoretical assumptions of the relation between Outstanding Designers' expertise and prototyping activities, are visualised in a model described in the following (in Figure 1).

The Model of Relation of Outstanding Designers' Expertise and Prototyping

The model focuses on the visualisation of core insights and assumptions supported by theoretical concepts from the research literature. The model is described from the top down. The first step in the model is the Outstanding Designers prototyping activity. The more prototyping activities, the more divergent ideas (Dow et al., 2011; Yang, 2005). The more divergent ideas, the greater complexity the designer must cope with. Research has linked high complexity to uncertainty and fear of failure (Dörner et al., 1994). Uncertainty can be accompanied by avoiding decision-making and being afraid to make mistakes. Thus, the complexity has to be reduced. The Outstanding Designers reported to visualise the results of own reasoning and reflection activities direct into quick and rough prototypes. We see evidence in the responses that the Outstanding Designers based on their experiences has more solutions and knowledge in their head. The Outstanding Designers can combine these elements of solutions in their head before starting to prototype. That is one approach to avoid complexity.

In the quotes were mentioned using a structured approach to reflection activities for gaining certainty. We gained the insights that an Outstanding Designer is aware of reflection based on prototypes. Moreover, the Outstanding Designers described a switch between reflecting and prototyping. A further quote shows evidence that there is awareness for cues of uncertainties described as 'questions' that are popping up when building prototypes. Therefore, we also see a tendency that verbalisation comes into

play when Outstanding Designers are talking about a reflective situation. The Outstanding Designers expressed a strong awareness of reflection activities related to prototyping.

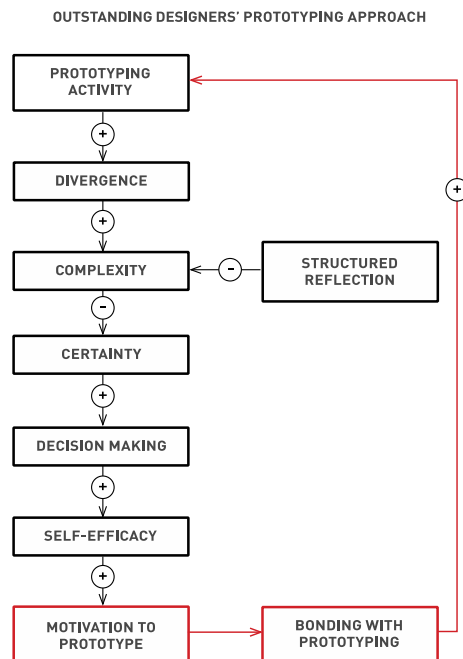


Figure 1. Relation between outstanding designers' expertise and prototyping

Furthermore, the description of going back and forth expresses a struggle for evolving the design, this can relate to prioritising and structuring criteria to come to a selection and making decisions. Some of the Outstanding Designers expressed a mindset of striving for high quality of their design that we designated as 'striving for success'. Therefore, we postulate that the Outstanding Designers reduce complexity in the design process by using reflective activities based on prototypes. We further assume that, through these activities, the Outstanding Designers gain certainty. Building on the answers, Outstanding Designers align the framing and its criteria with the design idea. This alignment is part of a structured approach to reflective activities and results in quicker decision-making. Reflective decision-making reduces uncertainty and increases certainty. We assume that, based on the evidence, high certainty results in a high-quality outcome. We argue that mastery experiences, in this case, solving complex problems based on prototypes in the design process, result in a high-quality outcome. These positive experiences lead, over time, to enhanced self-efficacy in solving complex problems based on prototypes. According to Bandura (1999), the greater the self-efficacy, the greater the motivation to select challenging tasks and complex problems. An increased self-efficacy impacts motivation, perseverance, and other behavioural elements beneficial for the quality of the design outcome. A strong attachment to prototyping supports the motivation to use prototyping more often. Experiences of high-quality outcomes emotionally reinforce this attachment. We refer to this behaviour as 'bonding with prototyping' and deduced an explanatory model of the relation between Outstanding Designers and their prototyping activities. We postulate that the described relation is a positive and self-reinforcing circle.

7. Conclusions

The interview study's aim is to explore the use of Outstanding Designers' prototyping. Based on seven interviews with Outstanding Designers, we determined the status quo of Outstanding Designers' prototyping activities and answered the research question (RQ 1): How do Outstanding Designers use prototyping in the design process? Based on the responses, we found indication that the Outstanding Designers are aware of the benefits and limits of using sketching and prototyping in their design process. Characteristic for their prototyping activities is that these are pivoting around a structured reflection approach and the motivation to gain certainty. Gaining certainty requires reducing complexity which is time and attention consuming and needs effort. In the quotes we found indication that Outstanding

Designers are using prototyping to follow their own high standards, to persevere facing complexity to strive for success. The main findings and theoretical assumptions from this study were synthesised for the deduction of a model. The model illustrates the relation between Outstanding Designers' expertise with prototyping (Figure 1). The explanatory model is preliminary and must be verified in the future. Nevertheless, we provide an additional research facet that contributes to a better understanding Outstanding Designers' expertise in their prototyping activities and the relation between them.

Acknowledgements

The structure, organisation, and results originate from the doctoral thesis 'Learning from Outstanding Designers: Exploring the Interplay of Design Expertise, Sketching, and Prototyping' (Jobst 2023).

References

- Bandura, A. (1999). Social cognitive theory: An agentic perspective. *Asian Journal of Social Psychology*, 2(1), 21–41.
- Blessing, L., & Chakrabarti, A. (2009). *DRM, a Design Research Methodology*. Springer London.
- Brown, T. (2009). *Change by Design. How Design Thinking Transforms Organizations and Inspires Innovation*. Haper Collins.
- Cross, N. (1998). The Expertise of Exceptional Designers. *Research in Engineering Design*, 10, Springer London, 141–149.
- Cross, N. (2001). Strategic knowledge exercised by outstanding designers. *Strategic Knowledge and Concept Formation*, III, 17–30.
- Cross, N. (2002). Creative Cognition in Design: Processes of Exceptional Designers. *Proceedings of the 4th Conference on Creativity & Cognition*, 14–19. <https://doi.org/10.1145/581710.581714>
- Cross, N. (2004). Creative Thinking by Expert Designers. *The Journal of Design Research*, 4(2), 123–143.
- Cross, N., & Lawson, B. (2005). Studying Outstanding Designers. Gero, J., Bonnardel (Eds.) *Studying Designers*, 283–287.
- Deininger, M., Daly, S. R., Lee, J. C., Seifert, C. M., & Sienko, K. H. (2019). Prototyping for context: Exploring stakeholder feedback based on prototype type, stakeholder group and question type. *Research in Engineering Design*, 30(4), 453–471. Carl Hanser Verlag GmbH & Co. KG
- Dow, S. P., Glassco, A., Kass, J., Schwarz, M., & Klemmer, S. R. (2009). The effect of parallel prototyping on design performance, learning, and self-efficacy. *Stanford Technical Report*, 10.
- Ehrlenspiel, K. (1995). *Integrierte Produktentwicklung: Methoden für Prozessorganisation, Produktentwicklung und Konstruktion*. Hanser Verlag.
- Gerber, E. (2009). Prototyping: Facing uncertainty through small wins. *DS 58-9: Proceedings of ICED 09, the 17th International Conference on Engineering Design, Vol. 9, Human Behavior in Design, Palo Alto, CA, USA, 24.-27.08. 2009*, 333–342.
- Gerber, E., & Carroll, M. (2012). The Psychological Experience of Prototyping. *Design Studies*, 33(1), 64–84.
- Goldschmidt, G. (2002). The backtalk of self-generated sketches. *Design Issues*, 19(1), 72–88.
- Jobst, B. S. (2023). *Learning from Outstanding Designers: Exploring the Interplay of Design Expertise, Sketching, and Prototyping*. <https://doi.org/10.4233/uuid:f557489f-ff75-4130-959b-39d258691bec>
- Kelley, T. (2005). *The ten faces of innovation: IDEO's strategies for beating the devil's advocate & driving creativity throughout your organization*. Crown business.
- Lawson, B. (1994). *Design in Mind*. Architectural Press.
- Lozoff, B., Brittenham, G. M., Trause, M. A., Kennell, J. H., & Klaus, M. H. (1977). The mother-newborn relationship: Limits of adaptability. *The Journal of Pediatrics*, 91(1), 1–12.
- OECD. (2022, July 9). *OECD Future of Education and Skills 2030* [Oecd.org/education/2030-project]. OECD Future of Education and Skills 2030. <https://www.oecd.org/education/2030-project/>
- Pahl, G., Beitz, W., Feldhusen, J., & Grote, K.-H. (2007). *Engineering Design: A Systematic Approach (Third Edition)*. Springer London.
- Pugh, S. (1991). *Total Design: Integrated Methods for Successful Product Engineering*. Addison-Wesley.
- Roy, R. (1993). Case studies of creativity in innovative product development. *Design Studies*, 14(4), 423–443.
- Sachse, P., Martini, M., Pinggera, J., Weber, B., Reiter, K., & Furtner, M. (2014). *Das Arbeitsgedächtnis als Nadelöhr des Denkens. Psychologie Menschlichen Handelns: Wissen & Denken—Wollen & Tun*. Pabst Science Publishers.
- Tollestrup, C., Laursen, L. N., & Vesti, H. N. (2023). Design Expertise: A Structured Literature Review. *DS 123: Proceedings of the Design Society: 24th International Conference on Engineering Design*, 1237–1246.
- Yang, M. C. (2005). A study of prototypes, design activity, and design outcome. *Design Studies*, 26(6), 649–669.