Design methods for collaborative knowledge production in inter- and transdisciplinary research

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Submitted by
Daniela Peukert
Born on 23.02.1985 in Leipzig, Germany

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First reviewer and main supervisor: Prof. Dr. Ulli Vilsmaier
Second reviewer: Prof. Dr. Daniel J. Lang
Third reviewer: Prof. Dr. Claudia Mareis

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Author's address:
Leuphana University, Faculty of Sustainability Science
Universitätsallee 1, 21335 Lüneburg, Germany
E-mail: daniela.peukert@leuphana.de | daniela.peukert@gmx.de

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Nihil est in intellectu quod non prius fuerit in sensu.

There is nothing in the intellect that has not previously been in the senses.

– John Locke –

Acknowledgements

When I presented my diploma thesis (a thick book with lots of pictures, illustrations and little text – very typical for a design thesis) at a conference in 2010, I was asked if it was a PhD. Since then, the seed had been sown in my head – but how little I knew. On the way to this PhD, I was supported by many people, whom I want to thank here. The journey starts with Gerhard Kampe, who laid the foundation for my interest in design research through his supervision of my diploma thesis in design. Benno Kotterba, who gave me, through the job at iAQ and himself, so many insights into research and beyond, and has always been full of support and confidence in me and my abilities. Our work at the institute was ahead of its time (today this is called 'new work'): it has promoted me and ruined me for all future employers. And Matthias Bergmann, who gave my research interest a decisive direction through his transdisciplinary perspective, the joint work in the project and by connecting me with Ulli.

I thank my three supervisors: Ulli Vilsmaier, Daniel Lang and Claudia Mareis. Working with you enriched me in so many ways and you complemented each other perfectly. Claudia, your work for and in design research is ground-breaking, you bring the most interesting people and strands of thought together, and I am very proud to write my thesis with you. Thank you for the time at the institute in Basel. Daniel, your curiosity and openness, coupled with many exciting projects and your friendly character, have always made working with you a pleasure. Ulli, thank you for your progressive understanding of research, your trust in me and bringing me to Leuphana.

During the Leverage Points project, I worked intensively with people in the case study regions. I am very grateful for this opportunity and thank them for their openness and hospitality. I also thank my colleagues from the Leverage Points team and the TD Methods group. You have been so wonderful in welcoming me, and your very different backgrounds and personalities have been so enriching. Rebecca, Ioana, Cristina, Andra, Sadhbh, David, Moritz, Guido, Philip – you were the best part of my time at Leuphana. Thank you for your support, your input, your open ear, your feedback and the good food. I especially thank you, Esther, for the path we have taken together, our diverse intellectual projects and the friendship that has grown out of it. Our collaboration will forever be my role-model of a shared intellectual journey.

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Prologue

Two interests led me to this PhD: first, I wanted to understand what design can do besides creating products; and second, I wanted to understand what design stands for and what it means to be a designer. For me, a key function for answering these questions lies within the design ('Entwurf'), so I wanted to explore its meaning and the knowledge it contains. My interest in studying these questions started when I handed in my diploma thesis – I had just finished my studies and was actually only at the beginning of my path of cognition. With my studies at a university of applied sciences and its orientation, I had received a very practice-oriented education as a designer, so I wanted to learn more about the theoretical and epistemological aspects of design. I decided to work as a designer and researcher in a small non-university research institute, with which I had already collaborated for my diploma thesis. In the five years of working in the small team there, I was able to get to know many aspects of research and started to think about a design research perspective.

When the institute received funding for a large research project on the mobility of older people, I came into contact with transdisciplinary research for the first time through the collaboration with Matthias Bergmann, an expert in this field of research. I noticed that there were many similarities to design and design research. I wanted to pursue this interest and began to formulate an exposé, which I sent to various professors and through which I finally ended up with my supervisors and at Leuphana University. My training as a designer has influenced my research approach in many ways: the integration of different (also practical) perspectives in the research context, an understanding of transformative research that changes subsequent conditions through its results, an iterative-experimental way of proceeding, and the high appreciation of visual-haptic gateways for the accessing of cognition. In finalising this work, I am deeply satisfied to have come a little closer to answering my initial questions. And at the same time, during my finalisation phase, the world is undergoing multiple crises – ecological, political, social, pandemic. There is much work to be done in designing interventions in the face of these complex problems.

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List of Articles

The following articles are included in this cumulative dissertation:

Article 1: **Peukert, D.** and Vilsmaier, U. (2019). 'Entwurfsbasierte Interventionen in der transdisziplinären Forschung'. In: *Interventionsforschung: Wege der Vermittlung – Intervention – Partizipation*, Ukowitz, M. and Renate, H. (Eds.), pp. 227–250. Wiesbaden: Springer Verlag. https://doi.org/10.1007/978-3-658-22048-8_10

Article 2: Meyer, E. and **Peukert, D.** (2020). 'Designing a transformative epistemology of the problematic: a perspective for transdisciplinary sustainability research'. *Social Epistemology*, 34(4), pp. 346–356. https://doi.org/10.1080/02691728.2019.1706119

Article 3: **Peukert, D**., Lam, D.P.M., Horcea-Milcu, A.I., Lang, D.J. (2021). 'Facilitating collaborative processes in transdisciplinary research using design prototyping'. *Journal of Design Research,* 18(5/6), pp. 294–326. https://doi.org/10.1504/JDR.2020.118673

Article 4: **Peukert, D.** and Vilsmaier, U. (2021). 'Collaborative design prototyping in transdisciplinary research: an approach to heterogeneity and unknowns'. *Futures,* 132. https://doi.org/10.1016/j.futures.2021.102808

Article 5: **Peukert, D.** (2022). 'Design-based approaches to collaborative knowledge production in transdisciplinary research'. In preparation for re-submission.

Contribution to articles:
All details on the specific contributions of all authors, weighting factors, publication status, and conference contributions can be found in Table 3 in Chapter 14.

Supplementary Publications not included in the Dissertation

Publications in the context of the case studies

This dissertation was embedded in the project 'Leverage Points for Sustainability Transformation' (see Chapter 3.2) at Leuphana University Lüneburg. The project also included two case study regions: the district of Oldenburg in Germany and Transylvania in Romania. I conducted research in both regions, working with local actors. In the context of this work, for each case study a book publication with a contribution by me was released. Although these articles are not embedded in my dissertation, they reflect my work in the regions and report on the cooperation with local actors.

Suppl. Chapter 1: **Peukert, D.** (2019). 'ReThink – ReStructure – ReConnect'. In: *Wie können '(Bio) Diversitätskorridore' im Landkreis Oldenburg ein nachhaltiges und zukunftsfähiges Leben nähren, fördern und antreiben?,* Artecology_net & Leverage Points, pp. 58–61. Lüneburg: Leuphana Universität Lüneburg. 978-3-935786-73-7

Suppl. Book 2: Fischer, J., Horcea-Milcu, A.I., Lang, D., ..., **Peukert, D.**, ... et al. (2019). *Balance Brings Beauty: Strategies for a Sustainable Southern Transylvania*. Sofia: Pensoft. 978-954-642-946-9

Further scientific articles

As a member of the research team and student of the Faculty of Sustainability, I had the opportunity to be part of a number of research collaborations. The resulting articles did not directly contribute to my dissertation, but they have taught me a great deal about different academic cultures, team work and writing scientific papers, and influenced my thinking about sustainability research during this time.

Suppl. Article 3: Lam, D.P.M., Horcea-Milcu, A.I., Fischer, J., **Peukert, D.** and Lang, D.J. (2020). 'Three principles for co-designing sustainability intervention strategies: Experiences from Southern Transylvania'. *Ambio,* 49, pp. 1451–1465. https://doi.org/10.1007/s13280-019-01302-x

Suppl. Article 4: Fam, D., Clarke, E., Freeth, R., Derwort, P., Klaniecki, K., Kater-Wettstädt, L., Hilser, S., **Peukert, D.,** Meyer, E., Horcea-Milcu, A.I. (2020). 'Interdisciplinary and transdisciplinary research and practice: Balancing expectation of the "old" academy with the future model of universities as "problem solvers".' *Higher Education Quarterly,* 74, pp. 19–34. https://doi.org/10.1111/hequ.12225

Suppl. Article 5: Fazey, I., Schäpke, N., Caniglia, G., …, **Peukert, D.,** … et al. (2020). 'Transforming knowledge systems for life on Earth: visions of future systems and how to get there'. *Energy Research & Social Science,* 70:101724. https://doi.org/10.1016/j.erss.2020.101724

Abstract

The way humans have shaped the world so far has led to various fundamental and complex problems that we are currently facing: climate change, biodiversity loss, pandemics. Transdisciplinary sustainability research addresses such complex problems by including a great variety of perspectives, forms of knowing and bodies of knowledge, including non-scientific ones, in the research process. Design, understood in an expanded sense as a creator of transformative processes, also turns to these 'wicked problems'. Based on their common concern, it is promising to bring both fields of research together productively. Therefore, this dissertation seeks to better understand how design methods facilitate collaborative knowledge production and integration in inter- and transdisciplinary sustainability research.

Through five independent papers, this dissertation contributes to addressing the research question on four levels – conceptual-epistemological, empirical, methodological and practical. By exploring the linkages between design research and inter- and transdisciplinary research, a conceptual basis for the targeted use of design methods in collaborative processes of inter- and transdisciplinary research is laid and their spectrum of methods is expanded. This is followed by the development of a transformative epistemology in and for problem-oriented, collaborative forms of research, such as transdisciplinary sustainability research, called *problematic designing*. Based on a deeper understanding of integration and collaborative knowledge production, as well as its accompanying challenges, empirical research into applying *design prototyping* as a method in and for situations of collaborative research was conducted. To this end, the findings provide a fundamental basis for the facilitation of inter- and transdisciplinary research processes when dealing with complex problems. With its inherent openness and iterative approach in addressing the unknowns of complex phenomena, *design prototyping* contributes to the required form of imagination that enables to anticipate possible futures. Furthermore, by including visual-haptic modes of expression, *design prototyping* reduces the dominance of language and text in scientific negotiation processes and does justice to the diversity of cognitive modes.

Finally, the empirical findings of this dissertation emphasise the importance of the visual-haptic dimension for collaborative knowledge production and the communication of knowledge, and provide insights into the visual structuring of human thought processes. The results on *material metaphors*, collaborative prototyping and *material-metaphorical imagery* contribute decisively to the basic knowledge of the epistemological quality of design and the importance of the visual and haptic for thought processes in general. The extension and adaptation of existing analysis methods in this dissertation add to the further development of analysis of visual-haptic data. The results are once again reflected in the synthesis of this framework paper as cross-cutting issues. With developing *design prototyping* as a design-based intervention and its integration into the epistemological perspective of *problematic designing* for inter- and transdisciplinary sustainability research, this dissertation makes an important contribution to addressing complex future-related problems and to creating change towards sustainability.

Keywords: inter- and transdisciplinary sustainability research, collaborative knowledge production, design research, design methods, design prototyping, design-based intervention, integration, problematic designing, complex problems

Zusammenfassung

Die Art und Weise, wie der Mensch die Welt bisher gestaltet hat, hat zu verschiedenen grundlegenden und komplexen Problemen geführt, mit denen wir heute konfrontiert sind: wie beispielsweise dem Klimawandel, dem Verlust der biologischen Vielfalt oder der Entstehung von Pandemien. Die transdisziplinäre Nachhaltigkeitsforschung adressiert derlei komplexe Probleme, indem sie eine große Vielfalt an Perspektiven, Wissensformen und Wissensbeständen, auch nicht-wissenschaftlicher Art, in den Forschungsprozess einbezieht. Auch das Design, verstanden in einem erweiterten Sinne als Gestalterin von transformativen Prozessen, beschäftigt sich mit diesen sogenannten „wicked problems". Aufgrund ihres gemeinsamen Anliegens scheint es deshalb vielversprechend, beide Forschungsfelder produktiv zusammenzuführen. In dieser Dissertation wird daher versucht, besser zu verstehen, wie Designmethoden die kollaborative Wissensproduktion und -integration in der inter- und transdisziplinären Nachhaltigkeitsforschung unterstützen können.

In fünf unabhängigen Artikeln trägt diese Dissertation dazu bei, die Forschungsfrage auf vier Ebenen zu beantworten - konzeptionell-epistemologisch, empirisch, methodisch und praktisch. Durch die Untersuchung der Zusammenhänge zwischen Designforschung und inter- und transdisziplinärer Forschung wird eine konzeptionelle Basis für den gezielten Einsatz von Designmethoden in kollaborativen Prozessen der inter- und transdisziplinären Forschung geschaffen und deren Methodenspektrum erweitert. Daran schließt sich die Entwicklung einer transformativen Epistemologie in und für problemorientierte, kollaborative Forschungsformen, wie der transdisziplinären Nachhaltigkeitsforschung, an, die als *Problematic Designing* bezeichnet wird. Ausgehend von einem vertieften Verständnis von Integration und kollaborativer Wissensproduktion sowie den damit einhergehenden Herausforderungen, wurde eine empirische Untersuchung zur Anwendung von *Design Prototyping* als Methode in und für Situationen kollaborativer Forschung durchgeführt. Die Ergebnisse liefern eine Basis für die Unterstützung inter- und transdisziplinärer Forschungsprozesse bei der Bearbeitung komplexer Problemstellungen. *Design Prototyping* trägt mit der ihm innewohnenden Offenheit und dem iterativen Ansatz in der Auseinandersetzung mit dem Unbekannten komplexer Phänomene zur erforderlichen Vorstellungskraft bei, die es erlaubt, mögliche Zukünfte zu antizipieren. Darüber hinaus reduziert *Design Prototyping*, durch die Einbeziehung visuell-haptischer Ausdrucksformen, die Dominanz von Sprache und Text in wissenschaftlichen Aushandlungsprozessen und wird der Vielfalt kognitiver Modi gerecht.

Die empirischen Ergebnisse dieser Dissertation unterstreichen die Bedeutung der visuell-haptischen Dimension für die kollaborative Wissensproduktion und -kommunikation und geben Einblicke in die visuelle Strukturierung menschlicher Denkprozesse. Die Erkenntnisse zu materiellen Metaphern, kollaborativem Prototyping und materiell-metaphorischer Bildsprache tragen zum Grundlagenwissen über die epistemologischen Qualitäten von Design und der Bedeutung des Visuell-Haptischen in Denkprozessen bei. Ebenso dient die Erweiterung und Anpassung bestehender Analysemethoden in dieser Dissertation der Weiterentwicklung der Analyse visuell-haptischer Daten. In der Synthese dieses Rahmenpapiers werden die Ergebnisse als Querschnittsthemen noch einmal reflektiert. Mit der Entwicklung von *Design Prototyping* als gestalterischer Intervention und deren Einbindung in die epistemologische Perspektive des *Problematic Designing* für die inter- und transdisziplinäre Nachhaltigkeitsforschung, leistet diese Dissertation einen wichtigen Beitrag zur Adressierung komplexer zukunftsbezogener Probleme und der Gestaltung von Transformationsprozessen in Richtung Nachhaltigkeit.

Stichworte: inter- und transdisziplinäre Nachhaltigkeitsforschung, kollaborative Wissensproduktion, Designforschung, Designmethoden, Design Prototyping, designbasierte Intervention, Integration, problematisierende Gestaltung, komplexe Probleme

1. Introduction

'one can see the world as a constant given cosmos, a given state in which we are incorporated. (...) one can understand the world as a process of development into which one is born. (...) and one can understand the world as a design. as a design, which means a product of civilisation, as a world made and organised by humans.'

(Aicher, 1991, p. 184, own translation)

In this quote, the designer Otl Aicher distinguishes three understandings of the world and the role that humans play within it: a constant cosmos, a process of development and a human-made design. In the first two understandings, the human being is a passive element, in the last an active creator. The quote incorporates two important elements that are fundamental to this work. On the one hand, an understanding of the world as strongly shaped by humans. In this way, Aicher to some extent anticipates an aspect of the Anthropocene understanding (Crutzen, 2002; Folke et al., 2021), which conceives humans as creators of a geochronological era of the Earth. His understanding of the world as a human-made design is disappointing and disillusioning because it shows us that the current crises are also human-made. But his understanding also gives hope because we can still change this condition. Which brings the second important element, the design, into play. Aicher sees design as a tool of empowerment, of creative action. And the quote also indicates a direction – designing to change the world.[1]

I find myself in agreement with Aicher's third understanding of the world, although I do not share his implied anthropocentrism, as I will explain later. Overcoming human-made problems cannot, in my view, be achieved by a merely anthropocentric mindset. However, I agree on his understanding of a world as highly shaped by humans and the optimistic idea of design as an empowering tool. It also connects to my initial question introduced in the prologue, which provided the impetus for this dissertation: if designing is such a powerful tool, what qualities, what knowledge lies in designs so that we can use them to create and change current situations in this world in a collaborative effort?

The way humans have shaped the world so far has led to various fundamental and complex problems that we are currently facing – climate change, biodiversity loss, pandemics. Transdisciplinary sustainability research, understood as a problem-oriented transdisciplinarity (Klein, 2014; Lang & Wiek, 2021), addresses such complex problems and tackles them in a transformative research mode (Wiek & Lang, 2016). Transdisciplinarity is characterised by including a great variety of perspectives, forms of knowing and bodies of knowledge, including non-scientific ones (Hirsch Hadorn et al., 2008; Lang et al., 2012; Norström et al., 2020), in the research process in order to deal with these complex problems. If design is understood as a tool to create ideas for a different world, it can be used in addressing such problems through inter- and transdisciplinary sustainability research. Thereby, design research contributes its knowledge about the creation of designs and their embedding in research processes. Based on their common concern, it is promising to bring both fields of research – design research and inter- and transdisciplinary sustainability research – together productively. However, the application of design and creative methods in inter- and transdisciplinary sustainability research has only just started to be explored (Pearson et al., 2018; Heras et al., 2021), as have the qualities of designs in relation to the

[1] In this dissertation, the term world is used synonymously with the term Earth, i.e. it refers to the planet.

integration into collaborative knowledge production processes (Sanders et al., 2010; Bjögvinsson et al., 2012; Simonsen & Robertsen, 2013). The canon of methodological approaches to addressing complex sustainability-related phenomena and their unknowns is still underdeveloped (Bammer et al., 2020). Furthermore, there is little understanding of how the heterogeneous perspectives of different actors within collaborative research processes can be made more visible and how the challenges of this collaboration can be better addressed (Miller et al., 2014; Gaziulusoy et al., 2016; van Kerkhoff & Lebel, 2015). Based on these issues and research gaps, I have developed the following research question for this dissertation:

How do design methods facilitate integration in inter- and transdisciplinary sustainability research to address complex problems?

Five subordinate questions have emerged from the overarching research question (see also Fig. 2):

7. How can design contribute to an epistemological perspective for inter- and transdisciplinary research?
8. How can design expand the methodological spectrum for inter- and transdisciplinary research?
9. What are the characteristics of collaborative knowledge production and how can it be supported by design?
10. What are the qualities of *design prototyping*[2], as a specific design method, and how do they facilitate integration and processes of collaborative knowledge production?
11. How should we deal with complex problems of sustainable futures that have high degrees of uncertainties and unknowns?

I situate myself as a designer in the field of inter- and transdisciplinary sustainability research and approach the research questions from this perspective. Based on the problem statement described in the previous section and the research gaps outlined, this dissertation aims to contribute to this field by providing a transformative methodology of design, by developing an epistemology through the lens of problematisation and with the help of the visual-haptic materiality of *design prototyping*, and by cross-fertilising the fields of research. For this purpose, I have identified research aims on four levels – conceptual-epistemological, empirical, methodological and practical – which are addressed in an overlapping manner by the five articles in this dissertation.

The aims at the **conceptual-epistemological level** include the opening up of design for inter- and transdisciplinary sustainability research and the development of a conceptual basis for the targeted use of design methods in corresponding research processes. Furthermore, this dissertation aims to expand the modes of language and text in knowledge production and for the communication of knowledge to include the visual-haptic dimension. Finally, the development of an epistemological perspective in and for problem-oriented, collaborative research forms. On the **empirical level,** this work aims to unlock the specific qualities of designs and to gain insights into how *design prototyping*, as a specific design method, contributes to integration and collaborative knowledge production in inter- and transdisciplinary processes. The **methodological goals** are to develop a design method to support collaborative knowledge production and integration involving heterogeneous perspectives, forms of knowledge and bodies of knowledge, to broaden the spectrum of methods in inter- and transdisciplinary research and to contribute to the further

[2] In this dissertation, *design prototyping* is defined as a method for individually or collaboratively constructing two- and three-dimensional designs out of low-cost materials to develop and visualise ideas (see also Chapter 5.1.4).

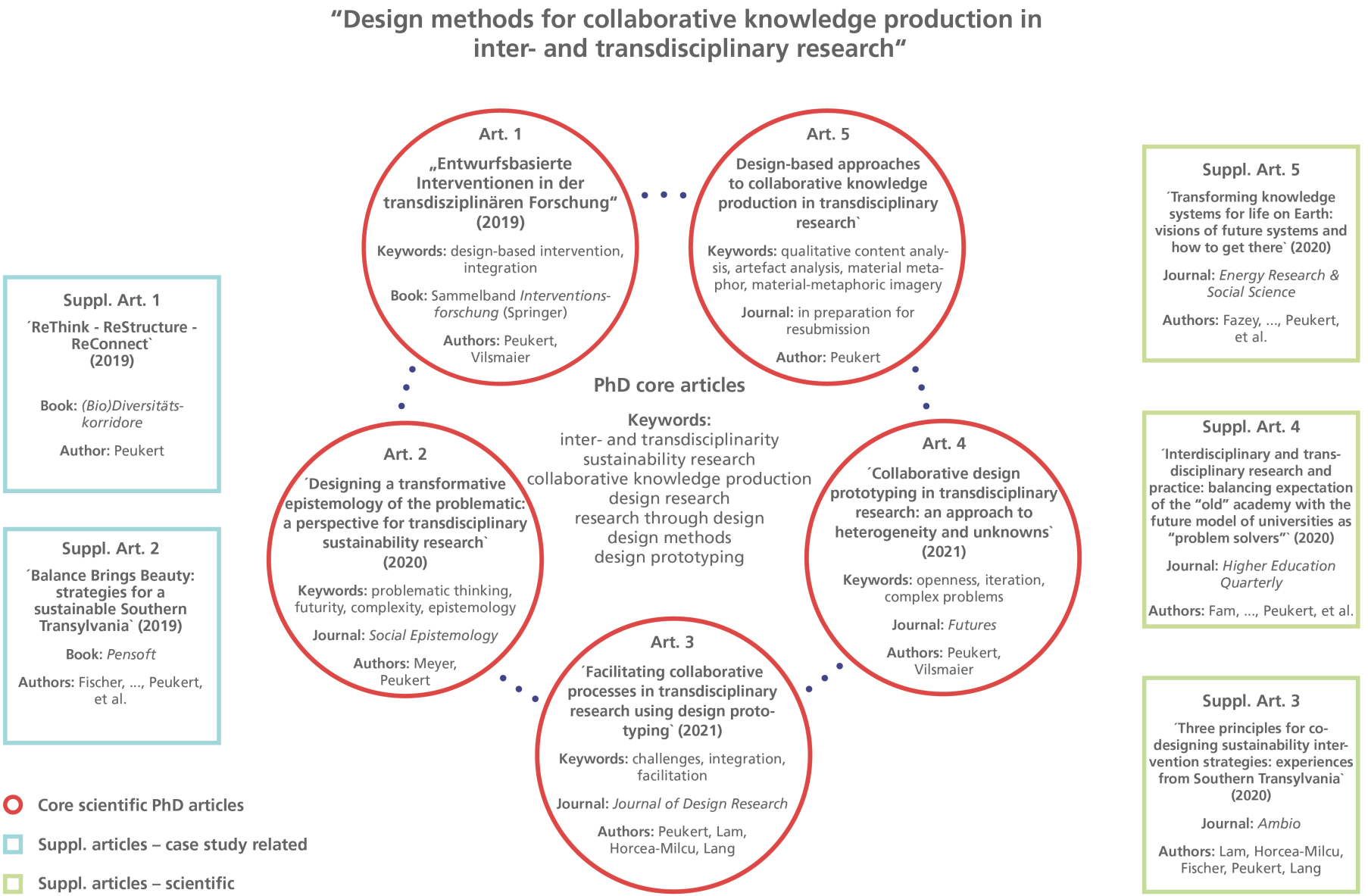
development of the analysis of visual-haptic data. The aim at the **practical level** is to extend the knowledge about facilitating collaborative research processes in addressing complex problems and related challenges. These results, formulated as research objectives, are once again reflected in the synthesis as cross-cutting issues.

The cumulative structure (see Fig. 1 for visual overview of the articles) of my dissertation is divided into five core articles (one book chapter and four articles in scientific journals). In addition to these, I contributed to five other publications that were written in the context of the project[3] (three articles in scientific journals) and its case studies (one article in a book about the work in the Oldenburg case study region and one jointly written book about the work in the Transylvania case study region). These articles are not part of my dissertation, but reflect my work in the case study regions and have influenced my thinking about sustainability research during the time of the project.

The framework paper embeds the five core articles as follows: after the introduction in this chapter, Chapter 2 explains the conceptual foundations of my dissertation. Since I work at the intersection of different fields – design research and inter- and transdisciplinary sustainability research – I give the broad audience in Chapter 2 a short, general introduction to them and then go into more specific detail about the aspects that are important for my work. I introduce design and design research, an extended understanding of design, and explain the perception of problems in design. Furthermore, I explain inter- and transdisciplinary research as a scientific principle, illustrate the role of complex problems in this field of research and give an introduction to sustainability research. Based on these insights, I present my methodological approaches in Chapter 3 by explaining my basic philosophical-epistemological positions, my embedding in the research context of the Leverage Points project and positionality, the collection and selection of my data, and their analysis. The results of each constituent article are briefly summarised in Chapter 4 (the articles in their original version can be found in Chapter 11). This is followed by a synthesis of the findings in three dimensions: Doing, Thinking and Reflecting. In the final Chapter 6 of the framework paper, I summarise the relevance of the results for design research and inter- and transdisciplinary sustainability research, point out potentials for further research and give an outlook on my future research agenda.

[3] This dissertation was embedded in the research project 'Leverage Points for Sustainability Transformation' (see also Chapter 3.2), which was carried out from April 2015 to March 2019 (https://leveragepoints.org).

Figure 1: Visual overview of the articles of this dissertation



2. Conceptual Background

2.1. Design and design research

The term design covers a variety of meanings. In its use as a noun, it describes various design and engineering disciplines as well as the designed object itself. The verb denotes the planning and creating aspects of the process-oriented action of design (Boradkar, 2010). Design as a profession has gained significant importance since the Industrial Revolution in the mid-nineteenth century and the commencement of machine-based production in factories (Bürdek, 2015; Rodgers & Milton, 2011). At that time, the design of form had become detached from manual production and became the task of professional designers. Through industrial and technological development, the discipline of design has strongly diversified. Today, it includes a diverse spectrum of sub-disciplines in areas such as fashion, graphics, communications, packaging, interfaces, services, interiors, and textiles (Erlhoff & Marshall, 2008). In addition to this classical understanding of design, a broader understanding of design has emerged. In this, design can be seen as a planning action that transforms 'existing situations into preferred ones' (Simon, 1969) using creative methods.

2.1.1. Expanded concept and domain of design

In an expanded concept, design moves between two poles, which Banz (2016) describes as 'design doing' and 'design thinking'. 'Design doing' primarily describes the making, i.e. the output-oriented, tangible practice of design, while 'design thinking' encompasses the cognitive, planning aspects of design. The term design thinking is discussed differently in two fields of discourse (Johansson-Sköldberg et al., 2013; Laursen & Haase, 2019; Mareis, 2011). In the design research discourse, design thinking or designerly thinking has been used since the 1960s to discuss how thinking and doing are interwoven in design. Johansson-Sköldberg et al. (2013) distinguish five different theoretical approaches to design thinking: the creation of artefacts, reflective practice, a problem-solving activity, a mode of reasoning and the creation of meaning. Since the early 2000s, the concept of design thinking has also received considerable attention in management literature, where the term is primarily understood as a human-centred innovation method (Brown, 2008; Plattner et al., 2012) for solving complex problems that can be undertaken as a process by anyone, including non-designers, oriented towards the way designers think and work (Carlgren et al., 2016; Brown, 2008; Kimbell, 2011). It is interesting that both discourses – design research and management – despite their different intentions and contexts, understand design as a problem-solving activity. This problem-solving understanding, which is widespread in design, will be discussed below. The meaning of 'design thinking' used in this dissertation is to be understood as standing in the tradition of the design research discourse.

As a result, design is no longer solely focused on artefacts, with its aesthetic and functional demands that go hand in hand with shaping forms, but on the transformative processes of planning and problem solving, which can also be applied in political or social processes (Escobar, 2018; Fry, 2011; Manzini, 2015; Papanek, 1971). Krippendorff (2011) describes this expansion of the design domain as a 'trajectory of artificiality'. In this trajectory, he outlines a path in which design problems are removed from the realm of products and evolve into services, interfaces, systems and projects, all the way to the design of discourses. This expansion of design activities is also reflected in Dorst (2019), who sees the future task of design in the creation of interventions to influence

systems. However, the expansion of the design domain brings up challenges that can no longer be addressed by a human-centred design paradigm. For example, socio-ecological problems cannot be tackled by solely focusing on people, as human-centred design does (Wendt, 2017), but must also give space to the complexity of these problems. One proposal in terms of a decentralised design is the concept of 'autonomous design' (Escobar, 2018) from South American anthropologist Arturo Escobar, who suggests letting each community practise its own design and renewing attention to materiality and non-humans. The impact of technological and ecological change challenges design to focus on complex socio-ecological-technical systems in which non-humans take over a new kind of agency (Forlano, 2017). Accordingly, design methods and practices must also evolve to better meet these challenges (ibid.).

2.1.2. The role of designs

Although the expanded understanding detaches design from the artefact, designs are still used in various ways within the design process. They are thus an essential part of the concrete practise of design. Designs serve various functions, such as visualisation, reflection, review and discussion of thoughts and ideas. Ideally, designs communicate a good sense of the idea, but also leave room for interpretation and further development (Lawson, 2005). Designs come in many forms, as sketches, drawings, mock-ups, models, prototypes, computer-aided design (CAD) presentations or renderings to name a few (Bürdek, 2015). Despite these seemingly different external forms, designs have in common the fact that they are manifestations of an idea that emerges in an iterative process of thinking and conceptualising and contains elements of future, uncertainty and provisionality (see Art. 1 and 4). Therefore, design processes do not work without designs, because many thoughts and decision-making processes are negotiated through them. However, designs can also be applied in contexts outside of design and thus be considered detached from the design process (Lawson, 2005). This is the case, for example, in certain communication or visioning processes where the goal is not necessarily the design itself. Or even in transdisciplinary processes, as explored in this work.

Designs serve as epistemic objects (Allert & Richter, 2009; Ewenstein & Whyte, 2009) in which thinking and doing relate to each other. Designing is a practice of knowledge production: through designing, the designing person understands the designed artifact and its underlying thoughts and ideas. A fundamental component of the knowledge-generating moment of designing lies in its visuality and tangibility. In design, different sources of knowledge merge and manifest as designed artefacts (Cross, 2001; Lawson, 2005), which differ from spoken language and text. Design thus transcends *'theory and practice and opens up not only a new reality but also new insights'* (Aicher, 1991, p. 195, own translation). Designs have both a procedural, open character and a finalised quality that is grounded in the materiality of the object. They thus materialise both as a process and as a product (see Art. 1). This reveals the dialectical nature of design. Designs have a specific temporal dimension, they are at once fixed and provisional, and contain a speculative element of future to deal with the uncertainty of the unknown in the present. In designing, a convergence between the now and the future, the actual and the possible, manifests itself in a search process (Bannon & Ehn, 2012; Dorst, 2015). Since there is no end to a design process and no final solution, design results in a future-oriented openness (Costa e Silva, 2018). We will never know under which conditions a design will be consulted or evaluated in the future (see Art. 2). However, because of the circumstances, the conditions, the design question and all the actors involved in the process, designing is a unique practice, highly situated and unrepeatable.

2.1.3. Research through design

An expanded understanding of design also means that design is increasingly involved in research processes. The understanding of design research underlying this dissertation is based on the concept of 'research through design', originally conceived by Christopher Frayling (1993) and later developed further by Alain Findeli (1998) and Wolfgang Jonas (2012). Frayling's (1993) original distinction is divided into research into, for and through design. Jonas (2012) further develops this triad into research about, for and through design. Research about design refers to a mode of looking at design from the outside, as is done in design history, for example. Research for design includes areas of knowledge that are useful to the design process, such as market research or user observations. Research through design refers to a concept that carries out research through the application or use of design methods and processes, such as drawing or prototyping. In doing so, the design researcher is directly involved in the research process and takes an active and formative role. Recently, questions in design research have revolved particularly around design as a cultural technique and the significance of design in the context of 'Mode 2' knowledge production (Mareis 2011). Mareis identifies three criteria for why design research is ideal-typical for Mode 2 knowledge production: its application orientation and 'practical relevance', the 'interdisciplinary orientation' and the 'precarious academic status' of design research.

2.1.4. Problem understanding in design

Since the 'Design Methods Movement' in the 1960s, and the upcoming influence of cognitive science on design, design was considered a problem-solving process by various authors (Archer, 1965; Rittel & Webber, 1973; Simon, 1969): *'[i]n our original examination of the nature of designing […], we stipulated the presence of a creative step as an essential element, distinguishing design from certain other problem-solving activities'* (Archer, 1965, p. 75). Problems are paradigmatically (Dorst, 2003) inscribed in the practise of design as the task that design strives to improve. It seems design is a whole discipline oriented towards problems and their solution (Cross, 2006; Dorst, 2003; Kimbell, 2011). Until today, authors tried to find out about the nature of design problems (Dorst, 2003), the role of methods and artefacts towards solving design problems, or the way in which problem spaces and solution spaces were getting closer to each other in circular processes (Jonas, 1993). Zdrahal also describes this in a similar way: *'[a] design process can be viewed as a sequence of problem re-representations gradually reducing problem indeterminacy'* (Zdrahal, 2007, p. 884). Buchanan (1992) describes the type of problems that design addresses as wicked problems in a Rittelian sense (Rittel & Webber, 1973) (see also Chapter 2.4).

In his article 'The Problem of Design Problems', Kees Dorst (2003) tries to find a structure for design problems in the design methodology literature and to develop a taxonomy for them. He comes to the result that a description of the design problem can never be complete and is therefore open: *'[t]his "openness" of a design problem is called the underdetermination of design problems'* (Dorst, 2003, p. 136). Dorst describes two main paradigms in design: design as a rational problem-solving process (Simon, 1969) and design as a reflective practice (Schön, 1983): *'The main paradigm of design methodology, in which design is seen as a rational problem-solving process, was introduced by Simon in the early 1970s. In this paradigm, design is viewed as a rational search process: the design problem defines the "problem space" that has to be surveyed in search of a design solution.[…] A radically different paradigm was proposed fifteen years later, by Donald Schön […], who describes design as an activity involving reflective practice'* (Dorst, 2003, pp. 137–138). Dorst tries to get closer to the structure of design problems by considering design to be a situated problem-solving activity

that cannot be understood without including social, cultural or physical conditions and the designing person themself. In 2019, Dorst himself advocated for a further development of the 'problem-solving' perspective in design. He calls for the complexity of problem situations to be taken as a starting point and for future design to no longer create solutions but to transform systems through intervention and the creation of new, exploratory design processes. *'(…) in really complex systems, newness comes from the emergence of order, rather than goal-directed creation; change is achieved through influencing the system, rather than implementation of a plan to solve the problem; a new state of relative stability can be achieved by creating resilience, rather than striving for an immutable structure – that so-called solution'* (Dorst, 2019, pp. 122–123). Although this concept offers a way of looking at design problems without the mechanistic logic of a linear problem–solution causality, or a logic of 'problem spaces' circularly approaching 'solution spaces', a comprehensive understanding of the term 'problem' in design is missing. It is still unclear what is considered a problem in general, who identifies it and who has the agency to solve it, taking into account the situatedness of each problem context.

This research proposes that the focus on design problems is too narrow to unfold the real potential of design. In narrowing one's gaze solely on design problems it is tempting to stay in a logic of mechanic solution finding: a detailed problem description already holds the path to its solution and possibly obscures the view on the existing phenomenon. However, establishing an epistemology of *problematic designing* (see Art. 2) might do justice towards the transformative potential of design – making phenomena visible, tangible and discussable through a nexus of conceptual thinking and creative doing, thereby bringing about change and promoting new insights – and enable a gradual approach to the unknown of the future in openness.

2.2. Inter – and transdisciplinary research

In this dissertation inter- and transdisciplinarity are used as theoretical lenses as well as research approaches for dealing with complex problems in the field of sustainability research. According to the US National Academy of Sciences (NAS), interdisciplinarity is understood as *'(…) a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice'* (NAS, 2005, p. 2). Since collaborative research is particularly important to this research, I understand interdisciplinarity following Klein's (2010) taxonomy, as a collaborative interdisciplinarity. This understanding is already very close to the approach of transdisciplinary research, which will be explained in more detail below.

Transdisciplinarity is understood as a *'reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge'* (Lang et al., 2012, pp. 26–27). Klein (2014) distinguishes between three different discourses of transdisciplinarity: transcendence, problem solving and transgression. In the discourse of transcendence, transdisciplinarity is seen as a way of achieving a unity of knowledge. In the second understanding, the focus is on dealing with life-world problem situations. The third discourse of transgression aims at questioning dominant assumptions and results in democratic participatory knowledge production. Even if the terminology differs, all three understandings of transdisciplinarity focus on similar areas: unity of knowledge, solving life-world problems and a

broader perspective on knowledge production. In this sense, Engbers (2020) has derived four common characteristics of transdisciplinarity based on five definitions (Klein et al., 2001; Pohl & Hirsch Hadorn, 2007; Scholz, 2011; Jahn et al., 2012; Lang et al., 2012):

1. The orientation towards socially relevant, complex problems
2. The heterogeneity of the actors involved and their specific knowledge
3. Learning as part of the research process
4. An enhanced relationship between the actors involved with their specific knowledge.

The aspect of including heterogeneous perspectives is of particular importance for this work and considered a general research attitude in order to be able to comprehensively illuminate a complex problem. To enable the linking of heterogeneous ways of knowing and acting, an expanded repertoire of methods and explicit integration skills are required. The creation of conditions and spaces for collaborative thinking and acting is essential to enable team work and collaborative knowledge production in heterogeneous teams. Transdisciplinary research is particularly concerned with collaborations between researchers with different disciplinary backgrounds as well as between researchers and non-scientific actors (Hirsch Hadorn et al., 2008; Klein et al., 2001; Lang et al., 2012; Wiek et al., 2012). Collaborative approaches aim to uncover and negotiate heterogeneous perspectives, understand multi-layered situations, gain common ground for problem definition, and explore potential complementarities between different knowledge systems (Eigenbrode et al., 2007; Lam et al., 2020a; Roux et al., 2017; Tengö et al., 2014). The general structure of transdisciplinary research processes in sustainability research is based on the steps of problem constitution, collaborative research through co-production of knowledge, and its re-integration into societal and scientific domains (Hirsch Hadorn et al., 2008; Jahn et al., 2012; Lang et al., 2012). The principle of transdisciplinarity is often used in project-oriented sustainability research to address complex problems, accompanied by unknowns and uncertainties. In summary, transdisciplinary sustainability research can be understood as transformative, problem-oriented and, according to Spangenberg (2011), as a 'science of sustainability' (see also Chapter 2.3). Here, the attribute problem-oriented refers to an orientation of transdisciplinary research that does not necessarily aims at solving problems (as I criticise in Article 2 with the reduction of a linear problem-solution thinking or in the understanding of problems in design in Chapter 2.1.1 and 2.1.4), but rather the general turning towards a problem, for example in real-world contexts, and attempts to point out options, as suggested by Wiek and Lang (2016).

An important specification of collaboration and often-mentioned aspect of transdisciplinary research is the collaborative production of knowledge by different, also non-scientific actors (Lang et al., 2012; Hemström et al., 2021; Polk, 2015; Pohl et al., 2010). This changing understanding of science and knowledge production can be traced back to authors such as Gibbons et al. (1994), who used the term 'Mode 2' to describe a science system in transition. According to Chambers et al., six modes of co-production can be identified: *'(1) researching solutions; (2) empowering voices; (3) brokering power; (4) reframing power; (5) navigating differences and (6) reframing agency'* (Chambers et al. , 2021, p. 7–10). Based on Norström et al. (2020), knowledge co-production in sustainability research is understood as *'iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future'* (ibid., p. 2). Using the four principles they describe – *'contextual, pluralistic, goal-oriented and interactive'* (ibid., p. 3) – collaborative knowledge production is seen as a process that is situated in the specific context, recognises multiple ways of knowing and doing, clearly defines challenge-specific goals, and actively and continuously embeds learning and engagement.

A second key term that is often used in connection with collaborative knowledge production is integration. In transdisciplinary research, integration is described as the central methodological and cognitive process (Defila & di Guilio, 2014; Jahn et al., 2012; Pohl et al., 2008) for establishing novel connections between former unrelated entities (Jahn et al., 2012; Pohl et al., 2021). According to Pohl et al. *'integration is an open-ended learning process without pre-determined outcomes'* (2021, p. 23). For Jahn et al. (2012) integration is complemented by the practice of differentiation and distinguished into several dimensions – epistemic, socio-organisational and communicative integration. Both terms – knowledge co-production and integration – are often used in parallel and synonymously, but they differ and complement each other. While knowledge co-production describes a goal for different entities to work together, the term integration provides a first indication of how this co-production can take place, namely by interlinking these entities (Pohl et al., 2021). The relationship of collaborative knowledge production to integration can be compared with the relationship of knowing-that to knowing-how, as described by Bammer et al.: *'For research integration and implementation, "knowing-that" involves understanding what is required to deal with complex societal and environmental problems in an integrated way, such as knowing to look for interconnections with other problems and to explore political, economic, historical and other circumstances. "Knowing-how" involves knowing which methods or processes to use in a particular context, along with skills in those methods and processes, such as building a model to describe the problem, or processes for engaging decision-makers in discussing research results.'* (Bammer et al., 2020, p. 2).

2.3. Sustainability research

My design-based, transdisciplinary work is brought to bear in the field of sustainability research based on sustainability sciences (Clark & Dickson, 2003; Jerneck, 2011; Kates et al., 2001). Fundamental to understanding sustainability sciences is a description by Kates et al. (2001, p. 641): *'A new field of sustainability science is emerging that seeks to understand the fundamental character of interactions between nature and society.'* As approaches to and perceptions of sustainability sciences are many and diverse, I provide an orientation to the understanding on which this work is based. In order to locate the field, I will highlight three historical reference points and four characteristics of sustainability sciences.

In 1972 the findings of the expert group the Club of Rome were presented in the report 'Limits to Growth' (Meadows et al., 1972). They predicted, on the basis of a computer simulation of world population, industrialisation and environmental pollution, the absolute limit of growth on Earth – and thus the end of resources – for the year 2072. This threatening scientific scenario raised awareness of the finite nature of resources and thus the need for sustainable management. To this growth-oriented diagnosis the report of the Brundtland Commission from 1987 adds an aspect of equity between present and future generations: *'Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future'* (World Commission on Environment and Development, 1987, p. 49). In 2015, the World Summit on Sustainable Development announced seventeen Sustainable Development Goals (SDGs) (United Nations, 2015), which emerged from a series of negotiations at the United Nations (UN) level and resulted in the 2030 Agenda for Sustainable Development. The goals include, for example, the fight against hunger and poverty, access to clean water and the preservation of life, land and water. The aim of these goals, which have been taken up by academia, non-governmental organisations and

public institutions since their publication, is to operationalise and implement different aspects of sustainability on local, regional and international scales.

In addition to the historical contextualisation, I point out four specific characteristics of sustainability sciences that form the basis of this research: normativity, an understanding of the 'science of sustainability', transformativity, and the involvement of different actors and forms of knowing. The fundamental normative orientation of sustainability sciences (Schneider et al., 2019) can be diagnosed at various levels. For example, Ziegler and Ott (2011) take up the intra- and intergenerational justice mentioned in the Brundtland definition and discuss ethical and value-related questions of sustainability. Popa et al. (2015) describe the normative aspect of sustainability problems and their scientific treatment: *'As a consequence, issues of global climate change or biodiversity loss do not enter the scientific realm as neutral objects of inquiry; they are from the very beginning (that is, from the phase of problem definition) value-laden and guided by a transformational perspective (envisaged progression towards a more desirable state of affairs)'* (Popa et al., 2015, p. 46). A second characteristic of sustainability sciences is the distinction introduced by Spangenberg (2011) between the concepts of 'science for sustainability' and 'science of sustainability'. The former corresponds more to an understanding of a traditional monodisciplinary science; the latter emphasises a transdisciplinary, reflexive and application-oriented research, which can also be located in a 'Mode 2' understanding of knowledge production (Gibbons et al., 1994). The transformative orientation of the theoretical embeddedness of sustainability sciences in this paper is described by Wiek and Lang (2016), who distinguish between two forms of sustainability research: descriptive-analytical and transformational. The first is primarily concerned with the description and analysis of complex, dynamic and cause–effect relationships of past, present and future sustainability problems. In this realm, systems thinking and modelling are dominant methodological approaches. The second type is primarily concerned with providing knowledge on how to successfully intervene in sustainability problems in order to solve or mitigate them. Solution options are actionable knowledge that contributes to real-world changes towards sustainability. With the intention of transforming problems into solutions, this stream has been called transformational (Wiek & Lang, 2016, p. 32). The fourth characteristic is the inclusion of non-scientific actors and their different forms of knowing in the research process (Clark & Dickson, 2003; Lang et al., 2012). Kates et al. highlight: *'Combining different ways of knowing and learning will permit different social actors to work in concert, even with much uncertainty and limited information'* (2001, p. 641). Thus, the participation of non-scientific actors is both a goal and a methodological aspect of sustainability sciences and also refers to the transdisciplinary approach to research.

2.4. Addressing complex problems

The problems that transdisciplinary sustainability research addresses have characteristic features. They are normatively charged, complex and have a high degree of unknowns that are accompanied by many uncertainties. The normative aspect of these problematic issues is expressed in two ways: in a request to change them for the better and through their value-laden character (Schmieg et al., 2017; Horcea-Milcu et al., 2019; Schneider et al., 2019). The complexity of problems in sustainability research is based on the fact that they often do not have a clear structure, they cannot be limited and have many different, interwoven causes. Their characteristics are thus very close to those of so-called wicked problems (Bammer et al., 2020; Klein, 2014). This term goes back to Rittel and Webber (1973) and describes problems that are difficult to deal with as they cannot be completely defined because the conditions of their emergence are always

incomplete and constantly changing. This principle of fundamental incompleteness forces researchers to navigate and assert themselves in uncertain and unknown terrain. These conditions require researchers to have methods and skills, such as the ability to recognise that a result or concept can only ever be seen as an intermediate step in an iterative loop of development. Complex problems are indeterminate and open-ended and therefore *'unpredictable, regardless of the capabilities of our epistemological [and methodological] toolbox'* (Grunwald, 2007, p. 257). Another specific research condition of complex sustainability problems is that they contain unknowns (Bammer et al., 2020), i.e. aspects that we do not yet know about. This describes a condition that makes it difficult to anticipate possible futures and requires a form of imagination that enables the exploration of what is not yet tangible. People often react to a state of the unknown with uncertainty (Grunwald, 2007), which means being insecure about the unknown and their own abilities. This can make collaborative work even more difficult.

In order to understand how transdisciplinary sustainability research addresses complex problems, one needs to grasp the existing understanding of problems in the field. Abson et al. (2017) are critical about the fact that sustainability problems are largely addressed from disciplinary perspectives that analyse problem dimensions separately and aim for quick solutions. In a discourse analysis, Meyer (2020) found that transdisciplinary sustainability research is constituted by a normative problem-solving orientation. The concept of 'problem' is largely determined by that of 'solution' and acquires its meaning primarily through integration into research process steps to create societal outcomes. In addition to a ubiquitous appeal to the multi-perspective identification of problems from the heterogeneity of actors involved, the transdisciplinary approaches found in the discourse exhibit a solution-oriented view of problems (Wiek & Lang, 2016). Wiek and Lang (2016) try to counter the reductive linking between problem and solution by not solving sustainability problems but intervening in them, postulating a real-world change towards sustainability instead of a solution and introducing the concept of solution options. These are characterised by being based on evidence-based, actionable knowledge, as complex as the problems themselves, requiring long-term processes involving real-world experimentation, and the need for collective learning and continuous adaptation (ibid.).

3. Methodological Approach

3.1. Methodological foundations

In this and the following chapters, I describe the context and foundations of the qualitative empirical research to analyse the qualities of *design prototyping*. Research design decisions and personal perspectives as well as the epistemological positions that drive them are explained in a more narrative fashion. Based on my training as a designer, I follow a design approach to research, also referred to as 'research through design' (see also Chapter 2.1.3): *'Research through design (RtD) is an approach to conducting scholarly research that employs the methods, practices, and processes of design practice with the intention of generating new knowledge'* (Zimmerman & Forlizzi, 2014, p. 167). Following this research approach and my interest in designerly knowledge (see prologue), I have accessed the subject of my research in an exploratory manner. Exploratory means an approach in the sense of an investigating search movement. This was also possible because design research as a new field of research is still forming and no dogmatically theoretical perspectives are represented, plus the field of transdisciplinary research is still consolidating. In the process, the explorative search movement intertwines theoretical (developing concepts and categories, terminological work, evaluating literature) and empirical approaches (preparing and conducting

workshops with *design prototyping*, individual and collaborative reflection on methodological processes) that complement each other and continue to refine each other in an iterative process. This oscillating search movement also points to the epistemic-transformative quality of design I described in Article 2, which I call a nexus of conceptual thinking and creative doing. In the course of my research, I have continuously narrowed down and specified my research question (Flick, 2019) in my engagement with the research object – the project-oriented work on complex problems in inter- and transdisciplinary sustainability research.

Another basic methodological position is that I understand transdisciplinarity not only as a field of research, but as a fundamental research principle. For me, knowledge production is unimaginable without the integration of heterogeneous perspectives, bodies of knowledge and forms of knowing. In the sense of the epistemology of *problematic designing* developed with Esther Meyer in Article 2, I see myself as a researcher who is part of the field to be researched. I perceive insights as preliminary designs in an open process, created in the context of their conditions and accompanied by the constant possibility of a radical break (see Art. 2). Since I have been working on a context-based and qualitative method with the further development of *design prototyping* in and for transdisciplinary research, it was natural for me to rely on qualitative methods for its analysis as well. In particular, the analysis of the visual-haptic material required an adaptation of the analysis methods (see Chapter 3.5 and Art. 5) that are mainly intended for the analysis of textual material.

3.2. Research context of the Leverage Points project

My dissertation was embedded in the research project 'Leverage Points for Sustainability Transformation' (LP) (Lang et al., 2014), which was carried out from April 2015 to March 2019 (https://leveragepoints.org). The project was an international, inter- and transdisciplinary research project, funded by the Volkswagen Foundation through the call for proposals focused on 'Science for sustainable development', and was based at Leuphana University Lüneburg. The aim of the project was to discover how complex socio-ecological systems can be transformed through leverage points, where a small change in one part of a system can lead to fundamental changes in the whole system (Meadows, 1999). The concept of leverage points is based on Donella Meadows' research on complex systems (Meadows et al., 1972). The concept includes twelve different leverage points, which are divided into 'shallow' and 'deep'. At 'shallow' leverage points, interventions are easily possible, but they have limited potential to bring about transformative change. At 'deep' leverage points, interventions are difficult, but have greater potential to bring about transformative change (Meadows, 1999). Leverage points can be categorised along the system properties they target: parameters, feedbacks, design and intention of a system (Abson et al., 2017). In the project, leverage points were explored through inter- and transdisciplinary approaches in three realms:

1. ReStructure institutions
2. ReConnect people and nature
3. ReThink ways and conditions of knowledge production.

The project included two place-based transdisciplinary case studies: one in Lower Saxony, Germany and one in Southern Transylvania, Romania. The aim of the Lower Saxony case study was to form alliances within a biodiversity corridor to develop sustainable pathways for the future of

the Oldenburg area. In comparison, the aim of the Southern Transylvania case study was to enable sustainability-transformation processes in Southern Transylvania, with a special focus on amplifying strategies to increase the reach of local sustainability initiatives. The transdisciplinary collaboration in both case studies included numerous working meetings, field trips of individual researchers and 23 workshops (10 in Lower Saxony and 13 in Southern Transylvania) with local actors. My research was located in the field of ReThink and also in both case studies. The transdisciplinary case studies provided the context for the created situations of collaborations in heterogeneous teams, in and with which I worked. My research contributed to questioning the production of knowledge and its conditions, to expanding the canon of methods of transdisciplinary sustainability research and to generating approaches for new epistemologies in this field of research.

3.3. Positionality

In order to understand my role and position in the research project, I was oriented towards the concept of 'dynamic positionality' by Freeth and Vilsmaier (2019). They understand the positionality of researchers within project teams not as static positioning but as being in constant movement. They distinguish three practices: *'dynamic proximity', 'critical reflexivity'*, and *'embedded relationality'* (Freeth & Vilsmaier, 2019, pp. 6–8). These practices of dynamic positionality involve active, critical and iterative engagement with one's own position, the research object and the relationship to the research team. A special feature of my research is that, coming from design research, I am fundamentally interested in the collaborative and transdisciplinary processes of research that address and try to contribute to solving sustainability issues, and so deeply immersed myself in the field of inter- and transdisciplinary sustainability research. Due to the interdisciplinary nature of the LP research project, in which I was the only designer, as well as the university environment of Leuphana, which does not teach any design courses, I had all the design freedoms, could enter the field undogmatically, and my design skills were appreciated in the project and by my colleagues. Furthermore, I intensively studied the literature on transdisciplinary sustainability research, taught transdisciplinary student courses and built up an understanding of different scientific cultures. In this interdisciplinary environment I had to be very clear about what contribution design research and my research work could make to the project in order to be able to articulate this to others. In my opinion, a clear picture of one's own disciplinary competences is the basis for inter- and transdisciplinary collaboration. Finding my way around a large international research project, with English as the dominant language of the project and of science and gaining an understanding of the cultures of origin of many international colleagues and project partners, sharpened my awareness of the importance and dominance of language in collaborative research processes – as well as the importance of finding alternative approaches to knowledge and exchange to go alongside language and text.

My role within the LP project was multifaceted: on the one hand I was part of the team, for example as a member of the ReThink work package, on the other hand I was also in an organising and facilitating role as a moderator of various workshops within the team and with team members in the case studies. I was the only researcher in the team who worked intensively with their research in both case studies. My epistemological position was also multifaceted: it involved being a learner in the project, but also enabling others to gain insights by creating the appropriate conditions. As organiser and moderator of the *design prototyping* workshops, I initiated and led them, but I also analysed the results and processes as a researcher. My privileged white, Central European research

perspective (Griffin & Braidotti, 2002) played a role in these situations. The accompanying power to steer the collaborative processes and the interpretative sovereignty over the results of the workshops must be critically examined (Wittmayer & Schäpke, 2014). At the same time, my background and perspective brought with it a limitation that can only be overcome through exchanges with participants and colleagues. Therefore, I try to make different perspectives visible with my research and methodological work and to expand the limitation of individual perspectives by obtaining a variety from different actors. Becoming aware of, and actively reflecting on, these different roles and positions in my research project was part of my immersive research process and a great learning experience.

3.4. Data collection and selection

During the time of my dissertation, I conducted a total of 14 workshops (each 1–3 hours) with *design prototyping*. Some of them served as pre-tests (Nos 1 and 2) for testing the method and preparing the workshops in the case study regions. Others helped me to find out whether specific backgrounds of the participants (for example, only designers or sociologists, Nos 1, 2, 4 and 6) led to fundamentally different results. In other workshops I tested the combination of *design prototyping* with other methods such as graphic recording (No. 6) or with the inclusion of personas and scenarios (Nos 6, 10 and 12). I tested how the method can be used to reflect and discuss presentations at conferences (No. 6) and how the haptic aspect of the method can function in a completely digital workshop (No. 14). All workshops were photo-documented and audio-recorded. Some workshops included a written reflection by the participants or I interviewed the participants afterwards (Nos 1, 2, 3, 5, 10 and 11). The selection of the workshops for the analysis and detailed description of the method (see Art. 3) was based on their function within the transdisciplinary research process and for the collaborative research work. The selected workshops (Nos 3, 5, 9 and 11) took place in the different case study regions and in different phases of a transdisciplinary process. They also represented different collaborative research activities: interdisciplinary team building, inter- and transdisciplinary visioning, collaborative reflection, visioning with a specific local actor group, and interdisciplinary sharing, disseminating and discussing of preliminary research results. For the detailed analysis of the empirical data by means of qualitative content analysis and artefact analysis (see Art. 5), workshops 3 and 5 were chosen because they each represent a case study region and one interdisciplinary and one transdisciplinary work.

Table 1: Summary of design prototyping workshops in which the data were collected

No.	Date	Context	Participants	Guiding question	Goals of workshop	Collaborative research activity
1	06/16	Design Research Conference, Brighton, UK	~20, mainly designers	What is your role in your team and organisation?	Reflecting about one's role and position	Collaborative reflection
2	06/16	PhDbyDesign Conference, Brighton, UK	~8, mainly designers	What is your role in your team and organisation?	Reflecting about one's role and position	Collaborative reflection
3	08/16	LP Team, case study Lower	~12, mixed scientists	How to bring together local needs, own and	Reflecting on connections to case study area,	Interdisciplinary team building

		Saxony, Lüneburg, GER		group research? How to get to know each other and respective research interests?	work package and own work. Discover the connecting potential.	
4	09/16	German Society for Sociology Conference, Bamberg, GER	~10, mainly sociologists	What are the presentations about?	Observing/ listening to lectures and building them with material. Afterwards discussing them with the presenter.	Collaborative reflection
5	09/16	LP case study Transylvania, RO	~28, local actors	How to bring together the work from different initiatives and make them visible?	Visioning about future of Southern Transylvania, reflecting own contributions, discussing joint contributions, formulating of a guiding question for the further project	Transdisciplinary visioning
6	11/16	German Society for Design Research Conference, Dessau, GER	~10, mainly designers	What could the agricultural future of a specific region look like?	Put participants into a persona role; discussing questions about perspectives; development of a joint strategy	Interdisciplinary visioning
7	06/17	LP case study Lower Saxony, Kirchhatten, GER	~10, mixed scientists, artists, regional actors	What would the ReThink aspect of your own work look like?	Reflecting the ReThink aspect of own work and discussing it	Transdisciplinary visioning
8	08/17	LP case study Lower Saxony, Kirchhatten, GER	~14, mixed scientists, artists, regional actors	What would the ReStructure and ReConnect aspects of your own work look like?	Reflecting on the ReStructure and ReConnect aspect of own work and discussing it	Transdisciplinary visioning

9	08/17	Transformations Conference, Dundee, UK	~8, mixed scientists	How to share research results and research experience and combine them with a new conceptual approach?	Reflecting on sustainability initiatives, their increasing impact and relation to amplifying mechanisms	Disseminating and discussing preliminary research results
10	09/17	ITD Conference, Lüneburg, GER	~20, mixed scientists	What could the agricultural future of a specific region look like?	Working with persona and future-scenario; reflecting on position and discussing the scenario	Interdisciplinary visioning
11	01/18	LP case study Transylvania, RO	~15, women from handicraft association	How to work together and develop the association in the future?	Reflecting on and communicating wishes for the association in the future (individual reflection, group discussion)	Visioning with a specific local actor group
12	02/19	LP Conference, PhD Day, Lüneburg, GER	~30, mixed scientists	What could a potential future research project look like?	Prototyping a common future scenario research project to solve a specific problem; reflecting on own role in it	Interdisciplinary visioning
13	02/19	PostDoc Academy, Lüneburg, GER	~20, mixed scientists	How does the current landscape of sustainability science and the researchers' position in this landscape look?	Reflecting position, discussing future	Interdisciplinary visioning
14	02/21	PostDoc Academy, online	~16, mixed scientists	How does the current landscape of sustainability science and the researchers' position in this landscape look?	Reflecting position, discussing future	Interdisciplinary visioning

3.5. Research methods and data analysis

The core of my research is methodological and unfolds in two ways in this dissertation: in the development of a design method applied in inter- and transdisciplinary sustainability research as the object of my research, and in the application of research methods for the analysis of the developed method. Having chosen *design prototyping* for its visual-haptic qualities, further methodological work revolved around the choice of appropriate documentation and evaluation methods to capture these very qualities. The progress of my papers shows how the method development has taken place: in the first papers the conceptual elaboration of the method took place, whereas later papers focused more on the empirical analyses of the method.

Table 2: Summary of the research methods used in the articles

Article	Type	Research methods
1	Conceptual	Literature review, facilitating *design prototyping* workshops, workshop reflection notes
2	Conceptual	Literature review
3	Conceptual	Literature review, facilitating *design prototyping* workshops, workshop reflection notes
4	Conceptual	Literature review, facilitating *design prototyping* workshops, workshop reflection notes
5	Empirical	Facilitating *design prototyping* workshops, workshop reflection notes, qualitative content analysis, artefact analysis

Table 2 gives an overview of which of the articles are conceptual and which are empirical in nature, and which research methods were used in addition to *design prototyping*. The data were collected by conducting workshops in which *design prototyping* was used (see Table 1). These were documented using a variety of media, each documenting a specific aspect. The prototyping process and the resulting design prototypes were documented through photographs. Some of the photographs also provided insights into the interaction of the participants with each other and with the artefacts. The entire workshops and prototyping processes were audio-recorded for each working table. This also made it possible to capture at least the verbalised aspects of the interactions. I noted my own impressions during the workshops in memos and in more detail in written notes after the workshops. The observations of my research colleagues, who supported me during the workshops, were written down by them or I noted them in feedback conversations. Participants in some workshops captured their thoughts in reflection sheets or were interviewed by me afterwards. Video recordings of the workshops in particular would have helped to visually understand the interaction of the participants with each other and with the artefacts (Tuma et al., 2013). Nevertheless, we decided against this form of documentation for reasons of trust building, as video recording creates a strong feeling of observation (Knoblauch et al., 2014), which we wanted to avoid, especially at the beginning of the cooperation.

When choosing the analysis methods, the focus was on being able to capture the visual-haptic quality of *design prototyping*. Therefore, I decided to use qualitative content analysis (Mayring, 2015) of the audio recordings of the process and the written documents, including the photographs, and artefact analysis (Lueger & Froschauer, 2018) of the prototypes created, as well as triangulation of both analysis methods. As the methodological procedure for using both analysis methods is described in detail in Article 5, I show here how the data and their analysis intertwined.

Notes on the analysis:

- The selection of codes for coding the material (first coding pass) in the content analysis was made on the basis of categories that emerged from my accumulated research experience of facilitating multiple workshops. In the course of the first coding pass, however, these codes proved to be not viable and I switched to a simpler coding of 'relevant'. The codes for the second coding round emerged from the results of the artefact analysis.
- During the qualitative analysis in MAXQDA, I repeatedly worked with memos, i.e. notes in which I informally captured my thoughts, impressions or striking points.
- As can be seen in Article 5, I did not analyse the entire, extensive material with the same intensity, but rather made selective decisions in order to narrow down the scope and at the same time to analyse the material in a comparative and contrasting way (both case studies, interdisciplinary – transdisciplinary, individual – collaborative prototyping, different working and status groups).
- The conditions for the existence of the artefacts were based on the participation of the producers in the workshops where they were asked to construct them. Time, prototyping materials, guidance for the prototyping process and workshop conditions (e.g. space, tables) were needed to produce the artefacts. The context of making the artefacts was the workshop situation. Making was intentional and desired, but still voluntary. Depending on the goal and project of the workshop, the making was individual and/or collaborative and no two artefacts were alike. The approach to making the artefacts was individual and depended on the task within the workshop and the ideas of the producers.
- Due to the focus on the visual-haptic qualities of the artefacts, I made specific adjustments to the methods of analysis. For example, I created text image collages so that analysis of the producers' description of the artefacts could be done simultaneously with viewing the photographs of the artefacts. Furthermore, I created posters on which the photographs of all the prototypes of one workshop to be analysed were mounted in an adapted grid in order to have an overall picture during the analysis. The third major methodological adaptation was the development of a specific list of questions (see Appendix of Art. 5) corresponding to the material to be analysed for the descriptive analysis part of the artefact analysis.
- The two methods of analysis intertwine and complement each other. Questions that remained open after the first part of the content analysis could be answered by findings from the artefact analysis and vice versa.

4. Results

This section presents the five publications comprising the dissertation (see also Fig. 1 for overview) and explains how each of them contributes to the overarching and subordinate research questions.

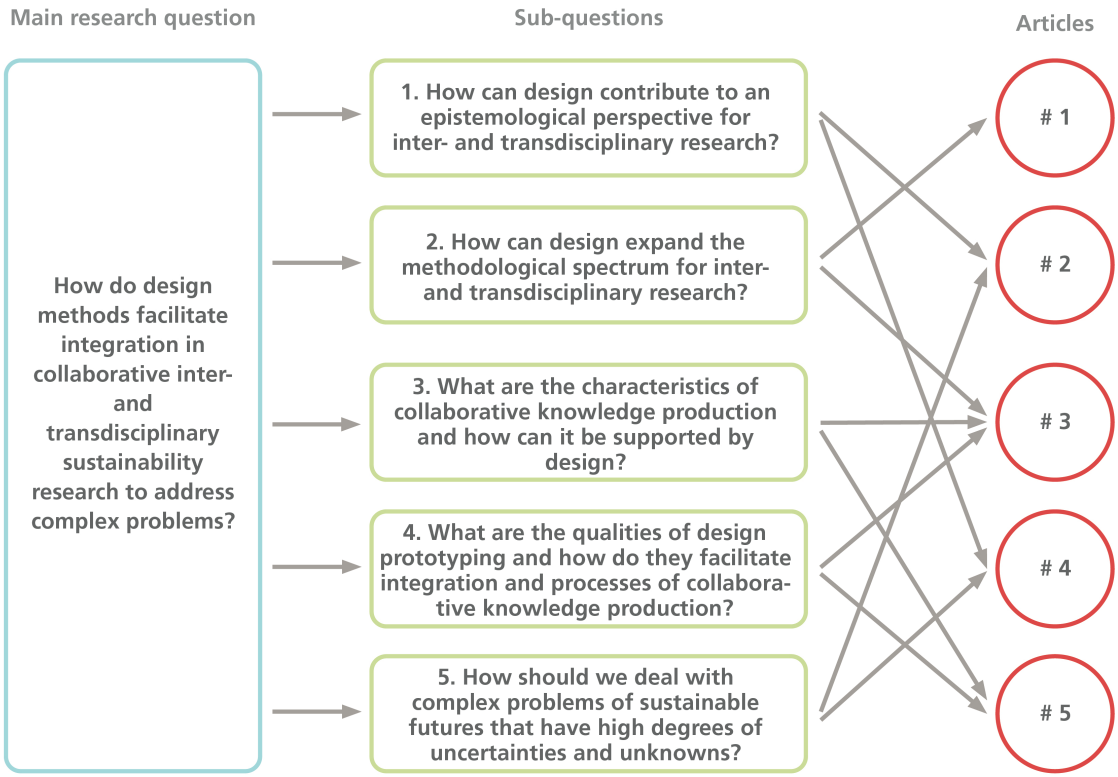


Figure 2: Presentation of the overarching research question with its five subordinate questions and how they are answered by the articles

Sub-question 1 operates on the epistemological level and is answered by Articles 2 and 4. Sub-question 2 addresses the methodological-facilitative level and is answered by Articles 1 and 3. Sub-question 3 focuses on the approach of collaborative knowledge production and is answered by Articles 3 and 5. Sub-question 4 focuses on the method of *design prototyping* to support collaborative knowledge production and is answered by Articles 3 and 5. Sub-question 5 asks about the normative goal of addressing complex problems and is answered by Articles 2 and 4.

4.1. Article 1 – 'Entwurfsbasierte Interventionen in der transdisziplinären Forschung'

Peukert, D. and Vilsmaier, U. (2019). 'Entwurfsbasierte Interventionen in der transdisziplinären Forschung'. In: Interventionsforschung: Wege der Vermittlung – Intervention – Partizipation, Ukowitz, M. and Renate, H. (Eds.), pp. 227–250. Wiesbaden: Springer Verlag. https://doi.org/10.1007/978-3-658-22048-8_10

Purpose of the article in this dissertation: The article opens up the commonalities of the two research fields of transdisciplinary research and design research.

Contribution to overarching research question: The article unfolds the understanding of design methods on which this dissertation is based and, with the help of an example from the case study in Romania, reveals how *design prototyping* can be effective in various dimensions of integration and also understood as an intervention in inter- and transdisciplinary research processes.

Research gap: The application of design methods in explicitly transdisciplinary processes has been little researched so far, as has their potential in relation to different dimensions of integration.

Argumentation: Transdisciplinary research approaches complex issues by including heterogeneous perspectives and forms of knowledge production, as well as different ways of knowing. This can lead to team constellations in which the participants come not only from science, but also from other areas of society. Greater diversity of the participants involved in the research process requires new forms of collaborative knowledge production. Different epistemic cultures, theoretical concepts and methodological approaches need to be bridged and integrated in order to find corresponding answers and to produce socially and culturally robust knowledge. This bridging requires an extended range of methods in transdisciplinary research. The article introduces the dissertation's underlying understandings of transdisciplinary research and an expanded understanding of design as well as the 'research through design' approach and unlocking the commonalities of both research fields.

Aim: The article develops a conceptual basis for the targeted use of design methods in inter- and transdisciplinary research processes and expands their spectrum of methods.

Summary of the key findings: The mutual reference and interweaving of both research strands based on their commonalities and orientation towards complex problems lays the conceptual foundation of my research. Based on an introduction to design research and transdisciplinary research, the commonalities of both research approaches are explored. These are a reference to 'Mode 2' knowledge production, an iterative approach and the addressing of so-called wicked problems. Due to the focus on these specific problems, a high degree of uncertainty, the inclusion of different fields of knowledge and the contextuality of the emerging research are further common features. Together with an insight into the process and methods of design, this framing serves to promote the transfer of design practices to support integration within transdisciplinary research processes. This is exemplified by a workshop example from the Romanian case study, in which the method of *design prototyping* was used. A concept of different dimensions of integration from transdisciplinary sustainability sciences (Jahn, Bergmann & Keil, 2012) serves as a base from which to investigate the epistemic, social-organisational and communicative integration capacity of this design method. The term design has a twofold meaning: an activity as well as an artifact. This means designs have both a procedural, open character and a closed nature, which is based in their object status. They therefore embody both process and product, externalise thoughts, and differ from spoken language and text due to their tangibility. The visuality, tangibility and spatial situatedness of designs enable the negotiation of different perspectives. These very characteristics seem to be appropriate to stimulate and promote knowledge integration amongst different participants in a transdisciplinary research process.

4.2. Article 2 – 'Designing a transformative epistemology of the problematic: a perspective for transdisciplinary sustainability research'

Meyer, E. and Peukert, D. (2020). 'Designing a transformative epistemology of the problematic: a perspective for transdisciplinary sustainability research'. Social Epistemology, 34(:4), pp. 346–356. https://doi.org/10.1080/02691728.2019.1706119

Purpose of the article in this dissertation: The article forms the scientific-theoretical basis of my dissertation by developing an epistemological perspective for transdisciplinary sustainability research called *problematic designing*.

Contribution to overarching research question: The article sheds light on problem orientation in transdisciplinary sustainability research and shows how design can contribute an epistemological perspective in this context. By developing the concept of *problematic designing*, an epistemological principle in design is traced and a scientific-theoretical foundation is developed, which in turn serves as a basis for the application of design methods in inter- and transdisciplinary processes.

Research gap: There is an ongoing discussion about the need to equip transdisciplinary research with a transformative epistemological foundation to face a planet-in-crisis mode.

Argumentation: The article develops a critical stance towards problem orientation in transdisciplinary sustainability research. By focusing on problem solving, the notion of control and manageability of knowledge or the research process is supposed. By taking up the philosophical concept of the problematic and interweaving it with design practice, an epistemological perspective is developed that, through its contextuality and status of being in the making, counters a hasty solution orientation. This is called a 'thinking practice of *problematic designing*', which describes an epistemological tool as well as a transformative process.

Aim: The article approaches problem pragmatism and, by incorporating design, opens an epistemological perspective in and for problem-oriented, collaborative forms of research, such as inter- and transdisciplinary sustainability research.

Summary of the key findings: In this paper, the philosophical concept of the problematic, which has been developed in a twentieth-century French epistemological tradition, is explained. There, the problematic is not about defining or questioning the problem, but about how knowledge is generated. Distinctive characteristics from the examination of the problematic are condensed and put into relation with design. Designing is constituted by a nexus of conceptual thinking and creative doing. As there is no end to a design process and no final solution, designing results in a forward-oriented openness. With this established link, designing is proposed as a creative practice that offers a pathway towards a transformative epistemology, in which thinking and doing are strongly interconnected. On this basis, the thinking practice of *problematic designing* is developed: its basic idea is to embed the practice of designing in the epistemology of the problematic. The following steps describe *problematic designing*: differentiate, detect, assess and design. These steps are continued in an open-ended, iterative process. Instead of a one-dimensional, solution-oriented directionality to eliminate problems that have been identified in the past, a variety of dimensions of transformation are inherent in a design. The following qualities are attributed to *problematic designing*:

- historical, socio-cultural, economic and political situatedness
- a process inherent in the living
- a permanent state of being in the making
- the transformative moment lies in differentiating the design from its epistemic conditions
- the designs can grow beyond their conditions of production.

Transferred to transdisciplinary sustainability research, knowledge can only be viewed in the tension between conditions of knowledge generation (e.g. heterogeneous actor relationships) and its results. The concept of *problematic designing* also brings up a general position in the theory of science: to understand research and its results as a design with the chance to redesign it at any time in the context of new findings. Accordingly, scientific knowledge is not final and always in the making.

4.3. Article 3 – 'Facilitating collaborative processes in transdisciplinary research using design prototyping'

Peukert, D., Lam, D.P.M., Horcea-Milcu, A.I., Lang, D.J. (2021). 'Facilitating collaborative processes in transdisciplinary research using design prototyping'. Submitted to Journal of Design Research (in press)

Purpose of the article in this dissertation: The article describes the practical application of a specific design method, *design prototyping*, in four different workshop examples of a transdisciplinary research process.

Contribution to overarching research question: The article deepens the understanding of how *design prototyping* can be used in different phases and for different collaborative research activities within inter- and transdisciplinary research processes. It also provides information on how the method meets the accompanying challenges of collaborative knowledge production. Both aspects – knowing in which collaborative research activities *design prototyping* can be applied and how it addresses the accompanying challenges – are important elements for facilitating an inter- and transdisciplinary research process in the sense of the research question.

Research gap: There is still limited understanding and agreement about how the multiple perspectives of different actors can be made more visible in inter- and transdisciplinary research processes. Also, the potential of *design prototyping* for collaborative research in sustainability science and beyond has only been vaguely explored.

Argumentation: Collaborations between researchers with different disciplinary backgrounds, as well as between researchers and non-scientific actors, play an essential role in inter- and transdisciplinary research. This diversity is foundational for co-producing actionable knowledge towards sustainability transformation, yet requires an extended range of methods that foster and support collaboration. Design methods can contribute to this method expansion, support inter- and transdisciplinary research, and address challenges that arise in the process of collaboration. Four examples are used to illustrate the use of *design prototyping* and, by analysing them, how the method contributes to facilitating knowledge integration and collaboration between the variety of actors involved in such processes.

Aim: The article shows how multiple perspectives can be made visible in different situations of inter- and transdisciplinary research processes, and how *design prototyping* can facilitate these and cope with upcoming challenges. The supplementary material of the article provides a practical guide for conducting a *design prototyping* workshop independently. It includes hints for the general preparation, an example agenda, explanations of the individual steps, a moderators' and facilitators' guide, and a materials list.

Summary of the key findings: The article explores the application of a specific design method, *design prototyping*, as a creative method to support collaborative processes within inter- and transdisciplinary sustainability research and how it copes with upcoming challenges. *Design prototyping* is defined as a method to individually or collaboratively develop and visualise ideas, which can then be discussed and revised. By drawing on discourses of integration, mutual learning and co-production, six different interrelated challenge categories were identified: (1) diversity, (2) communication, (3) power, (4) epistemology, (5) personal and team, and (6) focus. *Design prototyping* was applied in four workshops that pertained to different phases of a transdisciplinary research process and represented typical collaborative research activities: interdisciplinary team building; transdisciplinary visioning; visioning with a specific local actor group; and interdisciplinary sharing, disseminating and discussing of preliminary research results. The description of each workshop comprises the respective context and the collaborative challenges the participants faced. The results of the workshops show that *design prototyping* seems to be effective in all interrelated challenging areas of collaborative research. Due to the qualities of the designed prototypes – process-object, visual-haptic, spatial and metaphorical – the challenges of collaboration can be addressed at different levels. Communicative and epistemic differences are bridged, power gaps are balanced, tensions in the team are overcome and a common focus is created – while recognising the value of different perspectives. In the discussion both the added value and the weaknesses of facets such as the craft-playful character, problems with the group situations, the limitations of the material and the contextuality of the methods, are described. *Design prototyping*, together with attentive moderation, facilitates knowledge integration and collaboration between the variety of actors involved in transdisciplinary processes. Thus, it actively contributes to co-creating socially robust and actionable knowledge as needed for future-oriented transformations, as well as its prerequisites such as trust, shared understanding and appreciation of the other.

4.4. Article 4 – 'Collaborative design prototyping in transdisciplinary research: an approach to heterogeneity and unknowns'

Peukert, D. and Vilsmaier, U. (2021). 'Collaborative design prototyping in transdisciplinary research: an approach to heterogeneity and unknowns'. Futures, 132. https://doi.org/10.1016/j.futures.2021.102808

Purpose of the article in this dissertation: The article dives deeper into *design prototyping*: it describes two of its specific characteristics – iteration and openness – and how these allow the method to deal with complex problems of sustainable futures that are characterised by uncertainties and unknowns.

Contribution to overarching research question: This article is also about the practical application of *design prototyping* in inter- and transdisciplinary research processes. However, it looks more closely at how the application of the method in these contexts differs from those in

design and how its specific characteristics help deal with complex problems of sustainable futures. The findings deepen the understanding of how to promote integration under complex and uncertain conditions.

Research gap: To date, there is still a lack of methodical approaches to complex phenomena that promote an approximation of the unknown while maintaining an attitude of openness.

Argumentation: Transdisciplinary research deals with complex problems of sustainable futures that come with high levels of uncertainties and unknowns. As there is a fundamental incompleteness in understanding complex problems due to their indetermination, in order to adequately deal with such phenomena appropriate methodological approaches are needed, which themselves are characterised by adaptability and openness. Design's characteristic of intertwining design thinking and design doing in an iterative manner generates a structural openness and is considered to be of great value when addressing such problems.

Aim: Research into complex sustainability problems requires a form of imagination that enables the anticipation of possible futures and what is not yet tangible. *Design prototyping* contributes to this and expands the methodical repertoire of inter- and transdisciplinary research. This paper lays the conceptual foundation for the application of *design prototyping* in such research and introduces the use of design methods with an inherent openness to address unknowns and uncertainties when dealing with complex phenomena.

Summary of the key findings: This paper departs from elaborating on the underlying understanding of design research and critical transdisciplinarity. Furthermore, common strategies of the research fields in addressing heterogeneity and unknowns are identified and examined. Critical transdisciplinarity acknowledges the value of different types of knowledge, taking into consideration their different epistemic qualities, related quality criteria and ways of knowing. It aims to create in-between spaces in which the uncertain can be negotiated, constituted in difference and created through integration. In this way, transdisciplinary research is conscious of the transformation of the research object through the involvement of its researchers. The circular character of both design and transdisciplinary processes means that the results of problem solving transform the conditions for each subsequent loop by iterating between thinking and doing, or between different team constellations. Here, a fundamental transformative moment and openness for research development are incorporated. This is followed by a description of the *design prototyping* method.

Applying *design prototyping* in transdisciplinary research differs in some ways from the use of prototyping in design disciplines. This concerns the role of the designer as not designing themselves, but facilitating the process; a greater heterogeneity of actors in the designing team; the focus of exchange and mutual learning, instead of on results or the verification of aesthetic-formal features; a closer link to the research setting; and a strong embeddedness in the process and therefore being only an intermediate step in the overarching research process. The iterative, open and playful character of *design prototyping* stimulates imagination and creates space for trial and error without closing down further development. The application of *design prototyping* in a transdisciplinary case study showed that in order to embark on the long journey towards sustainable futures multiple forms of openness are needed. In the case study these are openness to the different perspectives and interests of actors in the region, to the preconditions of trust

building in political or funding structures, and to a future that includes changing social, political, and economic conditions to enable sustainable regional development.

Design prototyping supports openness in three ways. First, at the level of the material: the flexibility to build any artefact with it, its modifiability, its lack of predetermined use and openness to interpretation, invites the free visualisation of ideas. Second, openness at the level of the *design prototyping* process allows for flexible adaptation to the overarching research process, case study context and research question. And third, openness at the level of the design prototypes themselves allows for multi-layered interpretation, a connective communication of ideas and continuous development, as design prototypes are open for modification and therefore never finished. *Design prototyping* is considered a practice with knowledge-generating and mediating qualities in addressing the uncertainties and unknowns of complex problems by making possible futures imaginable. The inherent character of openness of *design prototyping* contributes to the promotion of collaborative knowledge production through integration. What emerges is a co-produced artifact that may serve as a core element of boundary-work and as a starting point for rapprochement and mutual understanding, while at the same time incorporating differences and resisting them.

4.5. Article 5 – 'Design-based approaches to collaborative knowledge production in transdisciplinary research'

Peukert, D. (2021). 'Design-based approaches to collaborative knowledge production in transdisciplinary research'. Submitted to Sustainability Science (under review)

Purpose of the article in this dissertation: The article provides the results of the analysis of the empirical data and detailed insights into the metaphorical and epistemic quality of *design prototyping*.

Contribution to overarching research question: This paper analyses the specific qualities of *design prototyping* and its emerging artefacts, to show how these influence collaborative knowledge production and integration using exemplary case studies. Conclusions are drawn about how these advantages can be used for collaborative processes with heterogeneous groups in inter- and transdisciplinary research settings.

Research gap: To date, there is little understanding of exactly how visual-haptic methods contribute to collaborative knowledge production and integration in inter- and transdisciplinary research processes.

Argumentation: The integration of different forms of knowing and bodies of knowledge, as well as collaborative forms of knowledge production, seems particularly significant for the core of scientific work and inter- and transdisciplinary processes in sustainability research. The term integration provides a first indication of how this co-production can take place, namely by interlinking these entities. However, it remains unclear what this linkage can look like in very practical research terms. Furthermore, knowledge co-production and integration in heterogeneous teams bring up specific challenges. This is where existing methods for group negotiation processes, strongly based on language and text, reach their limits. To fill this gap, design-based

methods can be used. They expand the mode of language and text to include the visual and haptic dimension.

Aim: This paper emphasises the importance of the visual-haptic in knowledge production and for the communication of knowledge. The findings on qualities contribute to the knowledge of how *design prototyping* contributes at the epistemological level to integration and collaborative knowledge production in inter- and transdisciplinary processes. The article also provides insights into the visual structuring of human thought processes and contributes to the further development of analysis of visual-haptic data.

Summary of the key findings: This paper shows the application of *design prototyping* for knowledge co-production and integration in an inter- and transdisciplinary research process and analyses the collected data. First, the research context of the transdisciplinary case studies and the two workshop settings are described, which serve as a basis for the analysis of the empirical data. Second, the methodological approach of analysing the *design prototyping* dataset (consisting of the production process and the final prototypes) with qualitative content analysis, artefact analysis and the triangulation of both methods is presented. The qualitative content analysis sheds light on the production process and verbal descriptions of the producers. The artifact analysis goes beyond the linguistic dimension and opens up in particular the visual-haptic dimension of the prototypes for the evaluation. Third, the results of the analysis and specific qualities of *design prototyping* are provided.

The first result concerns the very practical creation of collaborative prototypes. Three different approaches can be distinguished: additive, integrative and emergent. The second result concerns the role of metaphors in *design prototyping*. The peculiarity of the metaphors that appear in *design prototyping* is that three-dimensional materials describe the source of the metaphors. This metaphor model is introduced based on the results and called *material metaphor*. In a *material metaphor* different categories can be distinguished, which serve as a source for the metaphor: (1) the material itself, (2) haptics, (3) texture, (4) shape, (5) colour and (6) other material properties. *Material metaphors* translate and transport knowledge and offer a connection to the knowledge of others. They can be seen as bridges that allow access to other levels of thinking because they appeal to many senses. The third result and second dimension in which metaphors come to light in *design prototyping* processes is in the different forms of representation and visual-haptic structuring of the ideas by the producers, which are called *material-metaphoric imagery*. Three different types can be identified: concrete-figurative, iconic and abstract-structural. This is followed by a discussion of the methodological approach and the results as well as the implications of the findings for knowledge integration and co-production in heterogeneous teams and in addressing the uncertainties of complex problems. Knowledge of the qualities of design-based methods, their influence on collaborative knowledge production, and insights into *material metaphors* and *material-metaphoric imagery* can make their selection more purposeful. It opens doors for the application of further creative and visual-haptic methods and raises their status. The findings reflect how knowledge can be expressed individually and collaboratively in a visual-haptic way. As a complement to the linguistic-textual dominance in the communication and production of knowledge, the results are of great importance for epistemology, the philosophy of science and the practice of collaborative knowledge production in research processes – and thus far beyond the design context.

4.6. Supplementary publications in the context of the case studies

In the course of the cooperation with local actors in the case study regions of Oldenburg and Transylvania, a book publication with an article by me was published in each case. These articles are not embedded in my dissertation, but reflect my work in the regions and report on the cooperation with local actors.

Peukert, D. (2019). 'ReThink – ReStructure – ReConnect'. In: Wie können '(Bio) Diversitätskorridore' im Landkreis Oldenburg ein nachhaltiges und zukunftsfähiges Leben nähren, fördern und antreiben?, Artecology_net & Leverage Points, pp. 58–61. Lüneburg: Leuphana Universität Lüneburg. 978-3-935786-73-7

In the article 'ReThink – ReStructure – ReConnect' I describe the collaboration with the artist Peer Holthuizen, the finding of a common starting point, and the planning, implementation and results of our two creative workshops at the project container in Kirchhatten designed by Peer. What impressed me most about working with Peer and the other artists was their haptic approach. This also encouraged me in my work, because I saw how strong the impression on people is when they encounter works, installations and artworks spatially or can even touch them and interact with them. This enables us to convey abstract topics like sustainability in a more tangible and emotional way. Through the collaboration itself, I was challenged in my thinking and actions, and I observed and learned new perspectives. This consisted of not pursuing my methodological-scientific approach so strictly, but leaving room for other approaches and observing what effects they unfold. In this way, the artistic works have opened up new perspectives and enabled memorable (mental and physical) experiences. For me, one of the most important insights from the cooperation and workshops was the confirmation of how important it is to create spaces for discussion and attention in order to discuss topics such as sustainability and regional development with each other personally.

*Fischer, J., Horcea-Milcu, A.I., Lang, D., ..., **Peukert, D.**, ... et al. (2019). Balance Brings Beauty: Strategies for a Sustainable Southern Transylvania. Sofia: Pensoft. 978-954-642-946-9*

My contribution to the book 'Balance Brings Beauty' was about presenting the different initiatives in Southern Transylvania and our cooperation. In particular, the women's initiative 'Viscri incepe' – a collective of women who, by knitting socks, gloves, jumpers, etc. and selling them, provide an economic livelihood for their families and, through the association, support various social initiatives in the village such as school trips, tutoring and health care. Conducting a *design prototyping* workshop together with the women on the future of their association was a very valuable experience and an important building block of my research.

5. Synthesis

In this synthesis, I will look at the results of my work in three ways. First, by explaining the cross-cutting themes of my work along the two elements of thinking and doing, second, by answering my research questions and third, by reflecting on my research process along epistemological, methodological, contextual and personal aspects.

5.1. The designerly nexus of thinking and doing

My interest in designs (German 'Entwurf') was the starting point of my research. In German, the word 'Entwerfen' comes from weaving (Pfeifer, 2010), in which a picture was created by weaving the threads. I take up this meaning of the word in order to weave together the strands of knowledge from my individual articles and put them together to form an overall picture. In Article 2, I described designing as constituted by a nexus of conceptual thinking and creative doing. My dissertation and its cross-cutting issues can also be understood along these two realms (see Fig. 3). The 'Thinking' realm of my research comprises the concept of *problematic designing*, the way prototyping addresses the unknown of complex problems, and the role of visuality and materiality in thought processes. Complementary to this, the 'Doing' realm includes the practical application of *design prototyping* as a method to facilitate collaborative knowledge production, aspects of the facilitation of collaborative processes in inter- and transdisciplinary research, as well as materiality and the analysis of visual-haptic data.

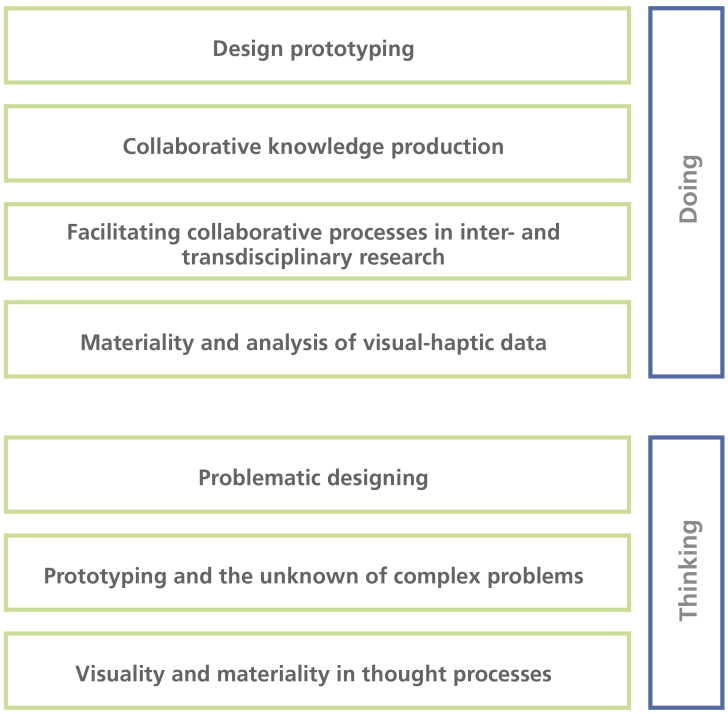


Figure 3: The cross-cutting issues of my dissertation in the realms of 'Thinking' and 'Doing'

5.1.1. Problematic designing

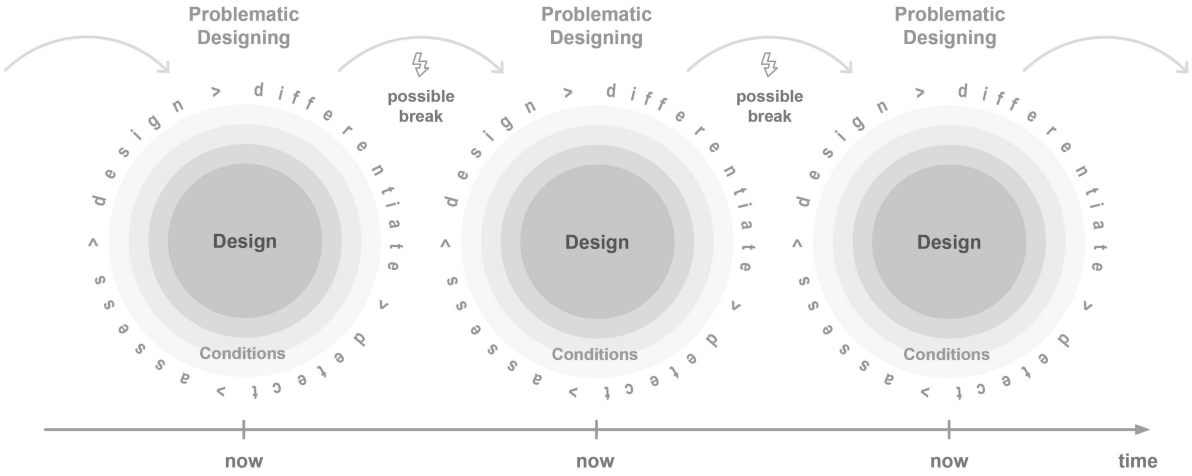


Figure 4: Visual representation of problematic designing

The most important contribution of this work in the realm of 'Thinking' lies in the development of a transformative epistemology as a perspective for transdisciplinary sustainability research and beyond (see Art. 2). In this epistemology, which we have called *problematic designing* (see Fig. 4*)*, we have brought together strands of knowledge from design research (Banz, 2016; Simon, 1969) and French philosophy on the problematic (Bachelard, 2012; Maniglier, 2012). In this epistemological stance, designs are embedded in their conditions of origin and are situated in the sense of Haraway (1988). The designs emerge in a permanent process of *problematic designing,* consisting of the steps differentiate, detect, assess and design. An adaptation to or a complete break with the conditions of origin is possible at any time. The problematic is the differentiation between the design and the conditions that generate it, and that in turn can be generated by the design. *Problematic designing* is iterative and open-ended. Since the designs are in a meta-stable equilibrium and permanent state of being in the making (Maniglier, 2012), there is no beginning or end on the time axis, but only a now. This represents an understanding of time that is constituted by being and is to be understood as an epistemological process inherent in the living (Scott, 2014). Accordingly, *problematic designing* always happens now, as the radical now is the coordinate point of the living being. The concept of *problematic designing* contains two elements that are especially important. Firstly, the epistemological relevance of design, constituted by the cognition in designing. Here, *problematic designing* can motivate the further expansion of the cognitive potential of design. And secondly, a philosophy-of-science stance in which research does not create irrefutable truths, but approaches knowledge embedded in the context of its conditions of origin in an iterative process. In this process, scientific knowledge, like a design, is to be regarded as a snapshot, 'always in the making' and always open to a break with its conditions of origin.

The particular challenges of the concept lie in its understanding of time and its practical applicability. *Problematic designing*'s understanding of time as a 'radical now' is difficult to integrate into current linear future-oriented and problem-solution related understandings of research. It is potentially more compatible with non-Western understandings of time (Parsons et al., 2016; Lam et al., 2020) and plays to its strength in transformative processes in local, indigenous contexts. In practical design, the concept of *problematic designing* still has its limits because of the permanent alignment between the design and its conditions, and the resulting metastability, the

understanding of time as a 'radical now' and the possibility of complete epistemological breaks. However, if a future practice of design is understood as designing interventions (Dorst, 2019) for change towards sustainability rather than designing solutions, *problematic designing* can also offer an epistemological perspective for design practice.

5.1.2. Prototyping and the unknown of complex problems

I have outlined the problematic nature of problem understanding in design research and transdisciplinary sustainability research in Article 2 and in sections 2.1.4 and 2.4 here. Both fields address complex problems, also called wicked problems (Rittel & Webber, 1973), which are characterised by indeterminacy, unknowns, their uniqueness and interconnectedness with other problems (see Art. 1). In order to deal adequately with such phenomena, an attitude of openness (Darbellay et al., 2014; Jacobs et al., 2018; Maguire, 2018) to new discoveries and observations and appropriate methodological approaches are needed (see Art. 4). Dealing with unknowns in particular describes a specific research condition that makes it difficult to anticipate possible futures. This state requires a form of imagination that enables the exploration of what is not yet tangible and methodological approaches to complex phenomena that promote an approach to the unknown while maintaining an attitude of openness. This is what I have explored with *design prototyping*.

The different qualities and characteristics of *design prototyping,* such as its playful nature, make it possible to materialise the unknown in the object and to stimulate the imagination of possible futures, to approach the unknown and make it accessible and tangible (see Art 3). *Design prototyping* can be realised as an iterative step-by-step approach to the unknown, as an exploratory approach to the problem of concern is created through the immanent intertwining of thinking and doing (see Art. 4). Prototypes can be seen as material objects that represent possible futures as tangible realities, helping us to deal with the unknowns of the future. The concept of *problematic designing* allows for leaving a chosen path and thus the emergence of an open future (see Art. 2). Unsustainable path dependencies show up in a moment of future orientation that is expressed in an accelerated flight forward towards productivity or a Sisyphean-like problem-solving activity. Instead, *problematic designing* allows futures to emerge by focusing on condition and design simultaneously. Weaving *design prototyping* and *problematic designing* into prototypical thinking and acting, they can be understood as gradual, iterative approaches to the unknown and complex problems in openness (see Art. 4). Even if this approach does not allow for a long-term view because of its experiential nature, the stable moment lies in the unstable. Nevertheless, *design prototyping* is a promising method to approach the unknown, which however, must permanently critically question and further develop itself in the sense of *problematic designing*.

If one takes up Escobar's idea of autonomous and pluriversal design (Escobar, 2018) and understands it as a form of diverse and decentralised design, the idea of problem and its solution can be seen as a centralistic one (collecting and sorting as much information as possible, etc.), which reaches its limits with the emergence of increasingly complex problems. Following this thought, complexity cannot be countered by focusing, but by decentralising to open the space to grasp and deal with the complexity. A decentralised design can be thought of on three levels:

- **Local:** In the sense of local designs for and by local communities, as proposed in Escobar's 'autonomous design' (Escobar, 2018).

- **Competence:** Decentralising design competence through the extension of collaborative design practices such as co-design (Eriksen, 2012; Sanders & Stappers, 2014) or participatory design (Björgvinsson et al., 2012; Simonsen & Robertson, 2013).
- **Entities:** The decentralisation of design's focus away from humans towards the inclusion of other entities in the sense of post-human (Forlano, 2017) or more-than-human design (Coulton & Lindley, 2019; Giaccardi & Redström, 2020).

In addition to decentralising design, another approach to addressing complex problems is to let go of the idea of their solvability. Therefore, two strands from design research and sustainability research are brought together here – they deal with the topic of intervention. Both Wiek & Lang (2016) and Dorst (2019) describe interventions as a way to address complex problems without remaining in a reductive link between problem and solution. To this end, Wiek and Lang (2016) introduce the concept of solution options by generating change towards sustainability with experimentation in practice and the need for collective learning and continuous adaptation. Dorst (2019) proposes intervention in situations of real complexity to move the whole system towards a desired state. He describes design interventions as an exploratory, reflexive practice approach with process steps of open framing of the complex problem situation, proposing possible solutions and reflecting on their effectiveness. In Article 1, I also refer to interventions and distinguish two types: *design of intervention*, which would correspond to designing interventions through design, and *design as intervention*, which would imply that all design activity is interventionist in character. Complementing these two, I propose a third category of *design-based interventions*, which emphasises the focus on the mediating and tangible-making quality of design. In the application of *design prototyping* as an intervention, the tangible-making happens in particular through the visual-haptic quality of the method. By developing *design prototyping* as a design-based intervention and its integration into the epistemological perspective of *problematic designing* for inter- and transdisciplinary sustainability research, this dissertation makes an important contribution to addressing complex future-related problems and a change towards sustainability.

5.1.3. Visuality and materiality in thought processes

As already mentioned in the point on materiality, the importance of the visual-haptic in cognitive processes permeates this research. It is an important complement to language and text in the collaborative production of knowledge (see Art. 1 and 3). In the results of this research, the visual-haptic is found not only in *material metaphors*, but especially in *material-metaphorical imagery* (see Art. 5). The three different visual language types – concrete-figurative, iconic and abstract-structural – can not only be thought of as forms of visual structuring of ideas, but can also as representing structures of thinking in general. Knowing how the other person structures their thoughts increases the understanding of their thought processes and builds bridges for joint knowledge-based collaboration.

The thoughts and results on the cognitive potential of the visual-haptic dimension of designs and artefacts allow comparisons to the concept of 'designerly ways of knowing' (Cross, 2006). This is how Cross describes design, as a third culture alongside the natural sciences and humanities, which deals with man-made, material culture. He understands that knowledge is inherent in objects as 'designerly' knowledge. Designers can both read and write this language of objects and thereby convey messages about objects. One can agree with Cross that this form of knowledge is of immense importance, but it does not necessarily need to be called 'designerly'. Designers may

be specially trained to speak this language, but due to the strong cognitive imprint of sensorimotor impressions of every human being, the ability to think in and with objects is possible for everyone – it is just rarely practised after childhood. It could rather be called a material-based knowing, which also corresponds to an understanding of knowledge, as something that is bound to entities (people, objects, actions, etc.) but is produced and negotiated by people as it is a human concept.

5.1.4. Design prototyping

In this dissertation *design prototyping* is defined as a method for individually or collaboratively constructing two- and three-dimensional designs out of low-cost materials to develop and visualise ideas. Any person without special technical knowledge or skills with all prototyping techniques allowed can do *design prototyping*. The prototypes do not have to meet aesthetic or functional requirements – instead they serve to reflect, revise, verify, visualise, communicate and discuss ideas. They allow for localisation and movement in space, and views from different perspectives (see Art. 3). Through its use outside the design context in inter- and transdisciplinary research situations, *design prototyping* can be understood as a method in the extended understanding of design (Krippendorff, 2011). The method promotes research processes in the sense of Research through Design (Frayling, 1993; Findeli, 1998; Jonas, 2012). The artefacts of *design prototyping* represent stable but open snapshots of a search process. They can be used to negotiate different perspectives in the sense of boundary objects (Klein, 2014; Leigh Star & Griesemer, 1989; Wyborn, 2015; Carlile, 2002; Heiss, 2020; Leigh Star, 2010; Salmi et al., 2012) as well as knowledge in the sense of epistemic objects (Allert & Richter, 2009; Ewenstein & Whyte, 2009).

The application of *design prototyping* in inter- and transdisciplinary research processes differs from the application of prototyping in design disciplines in six ways (see Art. 4):

1. The role of designer: when conducting *design prototyping*, the designer does not design themself, but is in the role of a facilitator or mediator who provides the space and tools, and guides and supports the participants in the prototyping process. So, everyone can be the designing person.
2. The context: the prototyping context is detached from design or a product orientation.
3. The heterogeneity of the actors: transdisciplinary team compositions can be far more diverse than those of product development teams.
4. The focus on exchange: in *design prototyping*, the focus is on exchange and mutual learning rather than on results or the verification of aesthetic-formal features, technical functionality or user acceptance.
5. A close connection to the research environment: compared with the design disciplines where prototypes are built by the designer or model maker, *design prototyping* in inter- and transdisciplinary research is more closely connected to the research environment and the problem at hand.
6. The process involvement: *design prototyping* is strongly embedded in the transdisciplinary research process and is therefore in itself only an intermediate step in the overarching frame.

Furthermore, *design prototyping* contains a fundamental openness which is evident on three levels (see Art. 4). First, at the level of the material: the flexibility to build any artefact with it, its modifiability, the lack of a predefined use and the openness to interpretation invite the free visualisation of ideas. Secondly, openness at the level of the *design prototyping* process allows for flexibility to adapt to the overarching research process, case study context and research question. And third, openness at the level of the design prototypes themselves, which allows for multi-layered interpretation, connective communication of ideas and continuous development, as design prototypes are open to modification and therefore never finished. The inherent nature of openness of *design prototyping* contributes to the promotion of knowledge co-production through integration. It can be understood as a design-based intervention method (see Art. 1) into complex problems of sustainability transformation. Therefore, a further linkage with emerging efforts and methods in arts-based sustainability research (Kagan, 2015; Pearson et al., 2018; Muhr, 2020) is desirable.

Although the method proved to be very helpful in the workshops, some limitations also became apparent (see Art. 3):

- Craft-playful character: due to the playful element of the method it may not be taken seriously. This prejudice can be countered by firm moderation, answering emerging uncertainties and questions at the beginning of the process, and by creating a trustworthy atmosphere where people are able to feel safe to explore unknows.
- Group situation: for some participants the workshop situation and presenting their own ideas was new and felt uncomfortable for them, especially when a visual language was rarely applied before in professional contexts. It might help to introduce or even add a task to strengthen and sensitize the aspect of visual-haptic storytelling to overcome the uncomfortable situation.
- Inequalities: although the linking of different phases within the *design prototyping* process (individual and collaborative prototyping, reflecting, listening, presenting) is intended to help ensure that as many voices as possible are heard in this process and that an equally designed result is sought, it cannot be ruled out that powerful or dominant ideas will prevail in the process. The central guidance of the process also entails the risk of interpretative sovereignty. This could be countered by involving different participants of the workshop in the interpretation phase.
- Limitations of the material: a few participants felt restricted in their expression due to the limited prototyping material. They reported that they find it much easier to express themselves through language. Here it is necessary to make clear that it is not about building something beautiful, but about the reflection and communication of thoughts.
- Non-human entities: in the *design prototyping* process, non-human entities gain greater attention and agency. However, the interpretation of the resulting prototypes is exclusively done by humans. So far, there are no methods or processes for involving non-human entities in the interpretation process. It is also not yet clear whether interpretation is a purely human concept.
- Contextuality: the resulting artefacts are not self-explanatory. This means that their interpretation cannot be independent of what is said about them. Furthermore, the ambiguity of the objects can overwhelm some participants, but this is also where the opportunity to connect to the thoughts and ideas of others lies. In this work, the extension of text and language in knowledge production processes through the visual-haptic quality

of *design prototyping* is strongly emphasised. However, the presentation, interpretation and analysis of the design prototypes is often still bound to text and language. This supposed contradiction must remain open at the end of the work.

5.1.5. Collaborative knowledge production

Collaborative knowledge production is a key element of inter- and transdisciplinary research (Lang et al., 2012; Hemström et al., 2021; Polk, 2015; Pohl et al., 2010). In order to specify the nevertheless abstract goal of the research and to be able to look at it more closely, I have examined four typical activities of collaborative research in Article 3: interdisciplinary team building, transdisciplinary visioning, visioning with a specific local actor group, and interdisciplinary sharing, disseminating and discussing of preliminary research results. Also in this article, by analysing different discourses I have identified six challenges that come up with collaboration in inter- and transdisciplinary research. These challenges regard aspects of diversity, communication, power, epistemology, personal and team, and focus. In processes of collaborative knowledge production design prototypes can be understood as non-human agents (Latour, 2005; Eriksen, 2012; Forlano, 2017; Hupkes, 2019). In the sense of the ambition to integrate different perspectives in transdisciplinary research processes, an integration of non-human actors would also be conceivable. Here, a first step could be taken with *design prototyping*. *Design prototyping* could also be used to establish stronger connections between collaborative knowledge production and existing research on co-design (Eriksen, 2012; Sanders & Stappers, 2014) or participatory design (Bjögvinsson et al., 2012; Simonsen & Robertson, 2013).

Design methods, and specifically *design prototyping*, are effective in collaborative knowledge production on different levels. Firstly, by supporting the principles of collaborative knowledge production as a form of knowing-that, and by contributing to the integration of different actors, forms of knowledge production and knowledge components in the sense of knowing-how by connecting the entities (see Art. 5). Secondly, *design prototyping* supports the six interrelated challenges (diversity, communication, power, epistemology, personal and team, and focus) of collaborative research identified in the discourses on mutual learning, integration and co-production (see Art. 3). Thirdly, because it complements classical methods of group negotiation, which are heavily based on text and language, with the visual and haptic dimension, reducing their dominance in communication and thus allowing access to different cognitive and emotional levels (see Art. 1 and 3). Finally, by transferring the findings on different forms of collaborative prototyping (additive, integrative and emergent) to other collaborative knowledge production processes as a possible general scheme (see Art. 5). As a normatively charged goal, collaborative knowledge production must be well moderated and accompanied as a process, and must not displace individual knowledge production and research work. A careful moderation balances the interplay of individual and collaborative knowledge production and takes the individual pace of people in such processes into account. If people in collaborative processes do not have time to follow their own pace, they cannot contribute to these processes with their full potential.

5.1.6. Facilitating collaborative processes in inter- and transdisciplinary research

As already described in the methodological reflection, the practical work in the project and for researching the *design prototyping* method also consisted to a large extent of the moderation and

facilitation of the collaborative processes in workshops. This included creating spaces and opportunities for collaborative work and guiding and supporting the participants in the prototyping process. My accumulated knowledge for facilitating collaborative processes in inter- and transdisciplinary research through *design prototyping* covers the following areas (see also supplement of Art. 3):

- The general course of transdisciplinary processes, like the process model with the phases of problem constitution, knowledge co-production and knowledge re-integration (Lang et al., 2012), and how to apply *design prototyping* in each phase.
- The appropriate selection and composition of the materials according to their colour, texture, tangibility, little predetermination, openness for modification, and sustainable/natural/artificial character.
- The composition of groups to create the most diverse teams.
- Facilitation skills: time management, agenda planning, and staffing of table and rooms.
- Moderation skills: guiding the prototyping process, answering questions, making sure everybody is heard, and leading the reflection phase.
- Composing the structure of the process with different prototyping elements, such as object-related warm-up, individual prototyping, collaborative prototyping, prototyping presentation, reflections and their adaption to different teams, aims, phases or collaborative research activities.
- Combining *design prototyping* with other methods such as scenario work or personas.
- Knowledge about the different challenges of research collaboration, such as diversity, epistemic, communication, power, personal and team, and focus challenge (see Art. 3) and how *design prototyping* addresses these.
- Knowledge about the use of *design prototyping* in typical situations of collaborative research, such as interdisciplinary team building, transdisciplinary visioning, visioning with specific local actor groups or interdisciplinary sharing, and disseminating and discussing of preliminary research results (see Art. 3).
- Adapting the tangible method of *design prototyping* to pure online workshops and the specific requirements that come with it.
- Knowledge about *design prototyping* as a method of boundary-work (Klein, 2014; Leigh Star & Griesemer, 1989; Wyborn, 2015; Carlile, 2002; Heiss, 2020; Leigh Star, 2010; Salmi et al., 2012).
- The documentation of the process.

Overall, collaborative knowledge production is not a self-running process and requires professional facilitation. Perhaps it is even conceivable to hire external facilitators, accompanying researchers or extend science management positions to support such processes in large teams. In any case, the awareness of such processes and their facilitation should be raised, especially as holding the double role of facilitator and researcher (Wittmayer & Schäpke, 2014) is barely possible due to the diametrically opposed responsibilities of keeping the big picture in view (timekeeping, motivation, making everybody heard, etc.) versus focusing only on specific aspects of the research aims.

5.1.7. Materiality and analysis of visual-haptic data

Materiality and tangibility played an important role throughout my research process and in the evaluation of the data (see Art. 5), starting with the choice of prototyping material according to their texture, shape, size, colour, materiality, haptic properties, formability and modifiability. Their low predefinition also played a role in that they can serve as an open projection surface for emotions and metaphors. For the interaction with the material, three significant interaction phases during the workshops can be named (see Art. 3). Firstly, at the beginning of the workshops, when the participants curiously looked at the material, touched it and began to tinker with it. Secondly, at the beginning of the respective prototyping, when the task was clear and the participants began to look for material for their first ideas, or were apparently guided by the material. And thirdly, when the participants explained their prototypes and used the material a lot to clarify their explanations. These phases could be described as periods of inscribing meaning or coding by the makers. On the other hand, there are periods of recepting or decoding of the material and prototypes by the other participants.

The following processes seem to take place when participants perceive the material or design prototypes (the order may vary) (see Art. 5): (1) recipient sees the material or design prototype and interprets the visual representation; (2) recipient forms own material metaphors; (3) recipient hears the producer's metaphors, reflects on them and mixes them with own metaphors; (4) recipient hears the producer's idea supported by the metaphors; and (5) recipient forms an interpretation of the prototype from this mixture. All participants of workshops are both producers and recipients of the design prototypes as well as coders and decoders of meaning, depending on the phase and task of the workshop. The material and prototypes are thus important non-human actors for the development and communication of ideas within the workshops. The ideas become physical objects and manifest as material actors. Here, future lines of connection can be drawn to the approaches of new materialism and posthumanism (Tsing, 2012; Haraway, 2008).

The visuality and haptics of the materials were recorded through photographs and the descriptions of the producers, and also played a major role in the evaluation of the data as they are decisive carriers of meaning. As described in Chapter 3.5, both analysis methods (qualitative content analysis and artefact analysis) had to be adapted in order to analyse the visual-haptic dimension (see Art. 5). Although I approached the visual-haptic dimension by creating text-image collages and analysis posters, in the end the exploration of meaning was again done via language or text, which leaves me somewhat unsatisfied. In my data analysis, the visual was a little easier to access than the haptic. But I suspect that it is precisely through the haptic that many emotional and material-metaphorical attributions of meaning are made, although they are little verbalised. Certainly, as already described in the methodological reflection, the video recording of *design prototyping* processes could reveal much more about the participants' interaction with the material and with each other. The dominance of language and text in collaborative research processes also continues in the evaluation of data. This is all the more astonishing when one knows about the great importance of sensorimotor skills for human cognitive development (Grunwald, 2008; Piaget, 1964) and discourses in the field of embodied cognition (Wilson, 2002).

5.2. Answering my research questions

In this chapter, I will provide compact answers to my five subordinate research questions and derive an outcome for my overarching research question 'How do design methods facilitate integration in inter- and transdisciplinary sustainability research to address complex problems?'.

1. How can design contribute to an epistemological perspective for inter- and transdisciplinary research?

Design can contribute to an epistemological perspective for inter- and transdisciplinary research on two levels. First, on a theoretical level through the epistemological concept of *problematic designing* (see Art. 2) and second, on the level of the method, through the supports of epistemic integration in inter- and transdisciplinary processes by *design prototyping* (see Art. 3).

2. How can design expand the methodological spectrum for inter- and transdisciplinary research?

Design expands the methodological spectrum for inter- and transdisciplinary research in three ways. First, by supporting the inclusion of visual-haptic methods in general; second, by applying *design prototyping* in particular; and third, by incorporating design method expertise at the level of process and collaboration.

3. What are the characteristics of collaborative knowledge production and how can it be supported by design?

In describing the characteristics of collaborative knowledge production, I draw on the principles of Norström et al. (2020), which are 'context-based, pluralistic, goal-oriented and interactive'. My research has shown that *design prototyping* becomes effective in all four principles. In general, design promotes collaborative knowledge production for example by using design methods. *Design Prototyping* as a specific design method supports collaborative knowledge production on four levels. First, by supporting the principles of collaborative knowledge production as a form of 'knowing-that', and by contributing to the integration of different actors, forms of knowledge production and knowledge components in the sense of 'knowing-how' by connecting these entities (see Art. 5). Second, *design prototyping* can be applied in different situations of collaborative knowledge production (interdisciplinary team building; transdisciplinary visioning; visioning with a specific local actor group; and interdisciplinary sharing, disseminating and discussing of preliminary research results) and addresses the resulting challenges (diversity, communication, power, epistemology, personal and team, and focus) (see Art. 3). Third, because of its visual and haptic dimension, *design prototyping* complements classical methods of collaborative group processes, which are heavily based on text and language, reduces their dominance in communication and thus allows access to different cognitive and emotional levels. Fourth, by transferring the findings on different forms of collaborative *design prototyping* (additive, integrative and emergent) (see Art. 5) to other processes of collaborative knowledge production, a possible general scheme for these processes could be developed.

4. What are the qualities of design prototyping, as a specific design method, and how do they facilitate integration and processes of collaborative knowledge production?

Design prototyping has four particular qualities that I found in the analysis (see Art. 3):

- **Process-object quality:** Design prototypes have an inherent process character, as well as an object status. This means they are at the same time becoming and completed. Therefore, the prototypes are never finished and can always be consulted at a later point in the collaborative knowledge production process. Furthermore, due to their objects status, design prototypes serve as artefacts on which different ideas or perspectives can be made visible, discussed and collaboratively further developed.
- **Visual-haptic quality:** As a material form of expression *design prototyping* complements language and text and reduces their dominance in communication. It opens up further cognitive accesses to the perspectives and knowledge of the involved actors and thus enables a multi-layered perspectivity, which is essential for the integration and collaborative knowledge production in transdisciplinary processes.
- **Spatial quality:** The spatial location of design prototypes enables the negotiation of different perspectives on them. As objects in the space, they function as additional actors in the group through whom and with whom one can communicate. This supports communication and levels power imbalances.
- **Metaphorical quality:** The visual metaphoric of design prototypes opens new gateways to thoughts beyond language. As seen in the results of the empirical analysis (see Art. 5) with the concepts of material metaphor and material-metaphoric imagery, the metaphorical quality of *design prototyping* builds bridges between different understandings of people with various background and helps to understand how people represent their ideas and knowledge. This in turn, facilitates the integration of different perspectives and supports the collaborative production of knowledge.

5. How should we deal with complex problems of sustainable futures that have high degrees of uncertainties and unknowns?

To deal with uncertainties and unknowns of complex problems, three characteristics are needed: imagination, iteration and openness. Research into complex sustainability problems requires a form of imagination that enables the anticipation of possible futures and what is not yet tangible. Here, design and design prototyping can help to gradually give form to what is not yet tangible. In addition, an iterative approach is necessary to approach complex problems step by step and to incorporate new insights into the next one at each of these steps. In this context, *problematic designing* can be seen as an epistemic strategy of constant questioning and iteration. Due to its indeterminacy, working on complex problems requires a great openness. An openness to new aspects of the problem gradually revealing themselves or to new insights and perspectives that can contribute to working on the problem. *Design prototyping* incorporates openness on three levels: of the material, of the design prototyping process and of the design prototypes themselves (see Art. 4).

Main research question: How do design methods facilitate integration in inter- and transdisciplinary sustainability research to address complex problems?

Design facilitates integration in inter- and transdisciplinary sustainability research on two levels. On an epistemological level, for example, by creating an epistemological perspective for inter- and transdisciplinary research through the concept of *problematic designing*. And on a research-practical-methodological level, by expanding the methodological spectrum of this research in general and by supporting collaborative knowledge production through the application of specific design methods such as *design prototyping*. *Design prototyping* acts in all principles of collaborative knowledge production, can be applied in different situations of collaborative research, meets its challenges and, through its specific qualities, creates new cognitive approaches beyond language and text. Furthermore, design addresses complex problems with its inherent qualities of imagination, iteration and openness.

5.3. Reflections on the research process

The reflection on the research journey of this dissertation is done in four areas: epistemological, empirical-methodological, contextual and personal. The epistemological research process was shaped by dealing with blurriness. As already described in Chapter 2, the two reference disciplines are themselves still differentiating. As a result, there were few predefined research paths to follow. This project commenced with the assumption that designing enables a form of cognition that can be useful for collaborative forms of knowledge production. The dissertation followed this epistemological research interest and approached an answer in different ways. Starting from designing as a form of cognition and transdisciplinarity as a research principle, an epistemology of *problematic designing* via problem understanding in design and transdisciplinary research (see Art. 2) was approached. In this framework, *design prototyping* is understood not only as an epistemological approach, but also as an attitude towards the philosophy of science. In this, research does not create irrefutable truths, but rather approaches knowledge embedded in the context of its conditions of emergence in an iterative process. In this process, scientific knowledge, like a design, is to be regarded as a snapshot, 'always in the making' and open to break with its conditions of emergence at any time (see Art. 2). In a context of epistemological blurriness, prototypical thinking and acting can establish an approach to uncertainty and complexity (see Art. 4). The concepts of *material metaphor* and *material-metaphoric imagery* that emerge from the analysis of the empirical data deepen the knowledge of how designing helps to contribute to the individual and collaborative process of knowledge production (see Art. 5).

Through the methodical support of the workshops in the case study regions with *design prototyping*, this work was able to contribute positively to the transdisciplinary process of the project (see Art. 1 and 3). Through the diverse workshops initiated, a broad pool of data (see also Table 1) was built up. The initial research into how design methods support integration in inter- and transdisciplinary processes was very broad. It gradually refined itself with the focus on the specific method of *design prototyping* and its qualities (see Art. 3). The initial attempt to identify dimensions of integration and how each can be supported by *design prototyping* proved unworkable, as these dimensions are highly intertwined in research practice. More helpful was the search for the challenges of collaborative research and how to address them through *design prototyping* (see Art. 3), and the open search for qualities of *design prototyping* in the artifact analysis of the empirical data (see Art. 5). In retrospect, the way *design prototyping* was used in the workshops was appropriate, as the method supported the goal of the workshop, the group and the

transdisciplinary research process in each case. Certainly, a specific adaption of the reflection sheets, the interviews or the documentation of the processes according to, for example, the use of *material metaphors* would have sharpened and shortened the research process.

From the context of the Leverage Points research project, two perspectives were important: ReThink (Lang et al., 2014) and Donella Meadows' 'leverage points' concept (Meadows, 1999). Both perspectives have been present in this research, as, for example, the ReThink working group shaped this work through reading literature together. This research substantially contributes to the expansion of findings on forms of knowledge production and the collaborative canon of methods of inter- and transdisciplinary sustainability research in the sense of ReThink. The core messages that have emerged from this research in terms of ReThink are:

- In order to address complex problems, collaborative knowledge production embedded in a new understanding of science and involving heterogeneous perspectives, forms of knowing, and bodies of knowledge is essential.
- Facilitating these collaborative research processes is helpful and a corresponding expansion of the canon of methods is necessary.
- The dominance of language and text must be reconsidered and complemented by other modes of expression, such as visual-haptic, in order to do justice to the diversity of cognitive modes.

Reflecting on the leverage points concept (Meadows, 1999) in relation to this research topic of collaborative knowledge production, knowledge in the concept of leverage points is very much operationalised as information and not considered as something fundamentally contextualised (Haraway, 1988), interwoven with different actors and other entities. Compared with the suggestion of an epistemology of *problematic designing* (see Art. 2), the concept of systems and levers seems very technical and little embedded in the conditions of its existence. Knowledge, understood in this way, and collaborative knowledge production can hardly be adequately represented in the concept of leverage points, or would lie across all leverage points.

The immersion into the research field mentioned in Chapter 3.3 worked very well in this case: it started with drifting into the field and project absorbing, then opened up an own field of activity. It took a while to develop a good understanding of the science, its field jargon and cultures, coming from the practical perspective of design and having a University of Applied Sciences (UAS) degree. It was great to be able to contribute to both case studies with this work and to get to know the local actors (see also the supplementary articles related to the case studies). The open welcome into the project and team led to much intellectual freedom. The opportunity to get to know so many different perspectives and collaborate with the people was enriching. Of course, some collaboration was also marked by misunderstandings at times and the diverse roles led to uncertainties, but these could be clarified through conversations, or could be endured, because they are also part of working in uncertain and complex processes. Knowing that I was able to find prototypical answers to the question that led me to this dissertation is deeply satisfying. And at the same time, so many new directions have opened up that will be enough for further research projects in the coming years and beyond. To have had the experience of diving into a completely new field, finding my way around it and walking out so much richer, with a changed view of the world and my research, is incredibly valuable. I started this project with an idea and left it with an attitude. I end this section with a quote from a colleague in one of my prototyping workshops: 'And

years later, I realised that actually science is fundamentally a creative art. It's about creating new understandings of the world.'

6. Conclusion

The overarching aim of this dissertation was to examine how design methods facilitate collaborative knowledge production and integration in inter- and transdisciplinary sustainability research. Through five independent papers, this dissertation contributed to addressing this research question conceptual-epistemological, empirical, methodological and practical. By exploring the linkages of the fields of design research and inter- and transdisciplinary research, a conceptual basis for the targeted use of design methods in collaborative research processes was laid.

This was followed by the development of a transformative epistemology in and for problem-oriented, collaborative forms of research, such as transdisciplinary sustainability research, called *problematic designing*. This concept forms the basis for a design-based epistemological and scientific stance. Based on a deeper understanding of integration and collaborative knowledge production, as well as its accompanying challenges, empirical research on applying *design prototyping* as a method in and for situations of collaborative research was conducted, thereby expanding the spectrum of methods in this field. To this end, the findings provide a fundamental basis for the facilitation of inter- and transdisciplinary research processes involving heterogeneous perspectives, forms of knowing and bodies of knowledge as needed when dealing with complex problems.

With its inherent openness and iterative approach in addressing the unknowns of complex phenomena, *design prototyping* contributes to the required form of imagination that enables us to anticipate possible futures and what is not yet tangible. Furthermore, by including visual-haptic modes of expression, *design prototyping* reduces the dominance of language and text in scientific negotiation processes and does justice to the diversity of cognitive modes. The empirical findings of the dissertation emphasise the importance of the visual-haptic dimension for collaborative knowledge production and the communication of knowledge and provide insights into the visual structuring of human thought processes. The results on *material metaphors*, collaborative prototyping and *material-metaphorical imagery* contribute decisively to the basic knowledge of the empirical quality of design and the importance of the visual and haptic for thought processes in general. The extension and adaptation of existing analysis methods in this dissertation add to the further development of the analysis of visual-haptic data.

The cognitive potential of the visual-haptic in design in this research holds linkages to further epistemological concepts such as tacit knowledge (Mareis, 2012; Polanyi, 1966), embodied knowledge (Shapiro, 2019; Wilson, 2002) and the epistemic quality of designs (Ewenstein & Whyte, 2009; Rheinberger, 1997), and thus great potential for further research. In this context, particular potential lies in the further empirical analysis of *material metaphors* as a promising bridge between the material-haptic world and language. Furthermore, objects as carriers of meaning with their inscribed knowledge, as well as the associated coding and decoding processes, are still little exploredrba in the context of transdisciplinary sustainability research. As already noticed in the analysis, there is still a lack of elaborate analysis methods that adequately cover the visual-haptic dimension of data. In Article 4, I was able to make a first attempt at how the unknown of complex

problems can be approached little by little through the openness and iteration of *design prototyping*. Since the nature of the challenges is not becoming less complex in view of current problem situations, it would be promising to further expand the concept of prototypical thinking and acting. This could serve as a basis for transformative research projects that work with transdisciplinary case studies or real-world labs (Bergmann et al., 2021). If one takes up this design field of action and understands design as a transformative practice in the context of social-ecological (Boehnert, 2018) and sustainable challenges, there is particular potential in further linking with the concepts of transition design (Irwin, 2015) and pluriversal design practices (Escobar, 2018).

For the outlook on a future research agenda, I would like to follow two conceptual lines: first, an understanding of collaborative knowledge production in transdisciplinary sustainability research that includes the most diverse perspectives, forms of knowing and bodies of knowledge. The aspects of diversity and the involvement of a wide range of actors are particularly important. Here, including actors other than people becomes relevant. I have already begun this involvement with designs and prototypes in my dissertation to some extent. If you think of further non-human actors, these could be for example animals, plants, rivers, materials, etc. The second strand of thought comes from design: in view of current problems, there are some initial movements in the design field to expand the old claim of good design as 'human-centred design', in which the human being is the measure of all things. Because good design for people, as we have learned, is not necessarily good for all other entities on this planet. Bringing both strands of thought together, the question is: how can design contribute to sustainable development including more than just human perspectives? This is the question I would like to address next in my research with a working title of 'more-than-human design for sustainability'.

7. References

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8. List of Figures

9. List of Tables

10. List of Abbreviations

Art.	Article
LP	Leverage Points (referring to the research project)
Suppl.	Supplementary

„Mit dem Entwerfen wird ein Ort geschaffen, der diesseits jeder sprachlichen Verfasstheit und abseits vertrauter Forschungspraxis liegt, und der als ein gemeinsamer Ausgangspunkt heterogener Teams gestaltet werden kann.“

11.Articles

11.1. Article 1

Peukert, D. and Vilsmaier, U. (2019). ‘Entwurfsbasierte Interventionen in der transdisziplinären Forschung‘. In: Interventionsforschung: Wege der Vermittlung – Intervention – Partizipation, Ukowitz, M. and Renate, H. (Eds.), pp. 227–250. Wiesbaden: Springer Verlag. https://doi.org/10.1007/978-3-658-22048-8_10

Entwurfsbasierte Interventionen in der transdisziplinären Forschung

10

Daniela Peukert und Ulli Vilsmaier

10.1 Einleitung

Die transdisziplinäre Forschung nähert sich komplexen Fragestellungen durch die Einbeziehung heterogener Perspektiven, Formen der Wissens- und Erkenntnisgenerierung und entsprechender Wissensbestände. Dies kann bei gesellschaftlich virulenten Themen zu Teamkonstellationen führen, deren TeilnehmerInnen nicht nur aus der Wissenschaft, sondern auch aus anderen Gesellschaftsbereichen kommen und durch ihre unterschiedlichen Rollen und Aufgaben entsprechend komplementäre Forschungsbeiträge erbringen können. Dabei besteht eine große Herausforderung innerhalb heterogener Projektteams darin, ein gemeinsames Verständnis dessen zu erlangen, was als Problem und anstehende Aufgabe erachtet wird sowie integrative Forschung zwischen PartnerInnen mit ihren spezifischen Expertisen zu ermöglichen. Eine größere Diversität aller am Forschungsprozess Beteiligten erfordert eine intensivere Kommunikation und neue Formen der kooperativen Wissensproduktion. Unterschiedliche Wissens- und Erkenntniskulturen, theoretische Konzepte und methodologische Zugriffe müssen überbrückt und integriert werden, um entsprechende Antworten zu finden und gesellschaftlich robustes Wissen zu erzeugen. Dieser Brückenschlag verlangt nach einem erweiterten Methodenspektrum in der transdisziplinären Forschung.

D. Peukert (✉) · U. Vilsmaier
Leuphana Universität Lüneburg, Lüneburg, Deutschland
E-Mail: daniela.peukert@leuphana.de

U. Vilsmaier
E-Mail: vilsmaier@leuphana.de

M. Ukowitz und R. Hübner (Hrsg.), *Interventionsforschung,*
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Der vorliegende Beitrag beleuchtet die Praxis des Entwerfens, ihr methodisches Vorgehen und transformatives Potential sowie das Wesen von Entwürfen, um sie für die Anwendung in der transdisziplinären Forschung fruchtbar zu machen. Unter einem Entwurf wird hier die Visualisierung einer Idee verstanden. Der Beitrag basiert auf einer mehrjährigen Tätigkeit in der Designpraxis sowie der Arbeit mit Entwürfen im Design und der transdisziplinären Forschung[1]. Dabei wurden vielfältige Erfahrungen hinsichtlich der integrierenden Eigenschaften von Entwürfen gewonnen und ein Interesse für deren fundierte wissenschaftliche Analyse angestoßen. Der Erforschung des Einsatzes von Entwürfen innerhalb transdisziplinärer Forschungsprozesse nähert sich der Beitrag aus der Perspektive der Designwissenschaft. Unter Design wird hierbei in einem erweiterten Verständnis des Begriffs ein planerisches Handeln verstanden, das mit unterschiedlichen gestalterischen Ausdrucksformen bestehende in wünschenswerte Zustände wandelt (Simon 1969) und somit über ein transformatives Moment verfügt. Zu diesem Zweck nutzen Designer Entwürfe zur Visualisierung von Ideen. Entwürfe haben sowohl einen prozessualen, offenen Charakter, als auch eine abgeschlossene Beschaffenheit, die sich in ihrer Objekthaftigkeit begründet. Sie verkörpern somit gleichsam Prozess wie auch Produkt. Im Idealfall liefert der Entwurf im Designprozess eine gute Vorstellung einer Idee und lässt gleichzeitig genug Raum für Deutung und Weiterentwicklung. Im Entwurf verbinden sich verschiedene Wissensquellen und manifestieren sich als gestaltete Artefakte. Damit übersteigt der Entwurf *„theorie und praxis und eröffnet nicht nur eine neue wirklichkeit, sondern auch neue einsichten“* (Aicher 2015, S.195). Im Designkontext treten Entwürfe in vielfältigen Erscheinungsformen zutage – als Skizzen, Zeichnungen, *Mock-up's*[2], Prototypen[3], CAD-Darstellungen[4] oder

[1]In folgenden Projekten konnten bereits Erfahrungen über den Einsatz von Entwürfen in transdisziplinärer Forschung gesammelt werden: „COMPAGNO – Personalisierter Begleiter“ (www.compagno-mobil.de), „ServaLink – Service-Assistent zur Verbesserung der Versorgungsstrukturen im ländlichen Raum“ (www.servalink.de), „Leverage Points for Sustainability Transformation“ (www.leveragepoints.org).

[2]*Mock-up's* sind Modelle aus preiswerten Materialien. Als erster Schritt von der Skizze zur dreidimensionalen Form dienen sie der Überprüfung eines Designs.

[3]Prototypen können in unterschiedlichen Qualitätsstufen angefertigt werden. Mit ihnen kann das Design oder bestimmte technische Funktionen überprüft werden. Häufig wird statt von Prototyp auch von einem Modell gesprochen.

[4]*Computer-aided design* (CAD) bezeichnet die rechnergestützte Konstruierung eines Produkts.

Renderings[5] – um einige wesentliche zu nennen. Trotz der unterschiedlichen Erscheinungsformen ist Entwürfen gemein, dass sie stets die Manifestation einer Idee sind, entstanden in einem wechselseitigen Prozess aus Denken und Entwerfen. Entwürfe dienen der Sichtbarmachung, Reflektion, Überprüfung und Diskussion von Gedanken und Ideen. Sie externalisieren Gedachtes und unterscheiden sich in ihrer Tangibilität von gesprochener Sprache und Text. Genau diese Eigenschaften scheinen geeignet, um Wissensintegration zwischen unterschiedlichen Beteiligten eines transdisziplinären Forschungsprozesses zu stimulieren und zu befördern.

Ziel des vorliegenden Beitrags ist es, eine konzeptionelle Basis für den zielgerichteten Einsatz von Entwurfsmethoden in transdisziplinären Forschungsprozessen zu erarbeiten. Ausgehend von einer Erläuterung des Verständnisses transdisziplinärer Forschung und der Designforschung werden gemeinsame Charakteristika der Forschungsfelder identifiziert und genauer beleuchtet. Dem folgt die Beschreibung und Analyse des methodischen Repertoires der Designforschung. Dabei wird auf Entwurfsmethoden fokussiert, die auf ihren partizipativen und intervenierenden Charakter hin ausgeleuchtet werden und erläutert, wie sie sich als Gestaltungsmittel in der transdisziplinären Forschungspraxis einsetzen lassen. Ein Konzept verschiedener Integrationsdimensionen aus den transdisziplinären Nachhaltigkeitswissenschaften (Jahn et al. 2012) dient als Grundlage, um Entwurfsmethoden auf ihre Integrationsleistung hin zu untersuchen. Dabei werden Entwürfe nicht als Zwischenschritte entlang eines Designprozesses auf dem Weg zu einem finalen Produkt begriffen, sondern das Entwerfen als eigenständige Praxis mit erkenntnisgenerierender und kommunikativer Qualität verstanden. Wenn man den Entwurf auf diese Weise betrachtet, lässt er sich vom Designkontext lösen, in seiner Vielschichtigkeit analysieren, auf seine vermittelnden Eigenschaften hin überprüfen und somit leichter in andere Anwendungszusammenhänge übertragen.

10.2 Verständnis von transdisziplinärer Forschung

Für die weitere Arbeit ist es notwendig ein klares Verständnis des Begriffs Transdisziplinarität zu erlangen, da dieser in unterschiedlichen Kontexten verschieden gedeutet wird. Julie Thompson Klein (2014) differenziert drei Diskurse, die sich

[5]Als *Rendering* bezeichnet man die fotorealistische Darstellung durch die computergestützte Berechnung von CAD-Daten (CAD) auf Basis von Rechenprozessen.

im Bezugsfeld Transdisziplinarität aufspannen: Transzendenz („transcendence"), Problemlösung („problem solving") und Transgression („transgression"). Hinter dem Begriff der Transzendenz verbirgt sich die Idee der Einheit der Wissenschaften mit dem Anspruch über die Grenzen einzelner Disziplinen hinweg ein ganzheitliches Verständnis der Welt zu erlangen. Der transdisziplinäre Diskurs rund um den Aspekt der Problemlösung greift die gemeinsame Wissensproduktion mit AkteurInnen anderer Gesellschaftsfelder zur Lösung anstehender Probleme auf. Dieser Ansatz wird von verschiedenen Institutionen weltweit verfolgt, deren Vorgehen sich durch unterschiedliche Arten von Einbindung von AkteurInnen differenziert. Das dritte Verständnis von Transdisziplinarität manifestiert sich nach Klein im Begriff der Transgression. Darunter wird ein Überschreiten vorherrschender Grundsätze und Annahmen im Kontext akademischer Wissenserzeugung verstanden und die hegemoniale Stellung von Wissenschaft in der Gesellschaft diskutiert sowie für eine Demokratisierung der Wissensproduktion eingetreten. Das diesem Beitrag zugrunde liegende Verständnis von Transdisziplinarität bezieht sich auf einen Modus von Forschung, der nicht an bestimmte Themenfelder gebunden ist. Es geht jedoch von Formen transdisziplinärer Forschung aus, die in den Nachhaltigkeitswissenschaften Anwendung finden und von Klein als Diskurs zur Problemlösung bezeichnet wird und sucht diese zu erweitern.

Im Fokus dieses Verständnisses von Transdisziplinarität steht dementsprechend die Verknüpfung einer gesellschaftlichen Problemstellung mit einer wissenschaftlichen Fragestellung. Deren Bearbeitung erfolgt idealtypisch in einem Prozess aus Problemkonstitution, gemeinsamer Bearbeitung durch Ko-Produktion von Wissen und Re-Integration des Wissens in gesellschaftliche wie wissenschaftliche Felder (Lang et al. 2012). Gesellschaftlich relevante Forschung und die Erzeugung sozial und kulturell robusten Wissens sind das Ziel dieses Forschungsmodus. Ein wesentlicher Aspekt dabei ist die Einbindung unterschiedlicher AkteurInnen aus Forschung und gesellschaftlicher Praxis, um ein besseres Problemverständnis zu erlangen und um zur Veränderung der Problemlage beizutragen, worin sich der transformative Charakter dieses Forschungsverständnisses zur Geltung bringt. Dies erfolgt durch das Erschließen entsprechender Perspektiven, Formen der Wissens- und Erkenntnisgenerierung sowie von Wissensbeständen und Positionen im Forschungsprozess. Weiterhin verspricht sich dieser Modus im Idealfall einen Beitrag zu wissenschaftlichen und gesellschaftlichen Diskursen zu leisten sowie zur Erzeugung beständiger Lösungen beizutragen.

Eine so verstandene transdisziplinäre Forschung geschieht in dem Bewusstsein, dass sich der Forschungsgegenstand durch die Involviertheit der ForscherInnen ändert. Des Weiteren ist diese Form der Forschung stark kontextbezogen.

Das heißt, dass die Kombination von Problemlagen, deren Kontextbezug und die Einbindung unterschiedlicher AkteurInnen in den transdisziplinären Forschungsprozess höchst singulär ist (Krohn 2008). Die Integration der am Prozess der gemeinsamen Problembearbeitung Beteiligten erfordert daher neue Fähigkeiten und Fertigkeiten von transdisziplinär Forschenden und stellt eine der wichtigsten Herausforderungen dieses Forschungsmodus dar (Jahn et al. 2012; Pohl et al. 2008). Unterschieden werden epistemische, sozial-organisatorische und kommunikative Dimensionen von Integration (Jahn et al. 2012). Unter epistemischer Integration wird die Identifizierung und Verknüpfung verschiedener wissenschaftlicher und außerwissenschaftlicher Wissensbestände bezeichnet. Auf der Ebene der sozial-organisationalen Integration sollen die unterschiedlichen Interessen und Arbeitsmodi der am Prozess Beteiligten expliziert und in Einklang gebracht werden. Die Dimension der kommunikativen Integration adressiert das Finden einer gemeinsamen Sprache als Basis des gegenseitigen Verständnisses. Dazu müssen unterschiedliche (fach)sprachliche Bedeutungen und kommunikative Praktiken identifiziert und zueinander in Beziehung gesetzt werden. Als konzeptioneller und analytischer Rahmen für die Realisierung und Erforschung von Integration innerhalb transdisziplinärer Prozesse erweist sich der Dimensionsdreiklang als dienlich, wenngleich eine Erweiterung um das Kulturelle der Wissens- und Erkenntnisproduktion sinnvoll erscheint (Vilsmaier et al. 2015). Erste eigene Erfahrungen in der Anwendung dieser Integrationsdimensionen wurden in einem transdisziplinären Forschungsprojekt zu Fragen der Klimawandeladaption gewonnen (Strasser et al. 2014). Die konkrete Ausgestaltung der Integrationsdimensionen, die methodische Adressierung, ihre Bezugnahme aufeinander und Eingliederung in die Schritte eines transdisziplinären Prozesses ist jedoch nach wie vor wenig ausdifferenziert. Um die Zusammenarbeit unterschiedlicher AkteurInnen und die Verknüpfung heterogener Wissensbestände überhaupt zu ermöglichen, bedarf es expliziter Integrationskompetenzen aufseiten der Beteiligten. Zudem wird auf allen Ebenen der Integration ein erweitertes Methoden-Repertoire benötigt, um kooperative Wissensgenerierung in heterogenen Teams zu ermöglichen. Über Methoden zum Erheben, Analysieren, Prozessieren, Modellieren und Interpretieren von Daten hinaus bedarf es allen voran der Methoden zur Herstellung von Bedingungen zum gemeinsamen Denken und Handeln sowie Methoden der Grenzarbeit, die das Differenzieren heterogener Positionen, Wissensbestände und Interessen wie auch deren Integration ermöglichen. Zu diesem Zweck sollen Designmethoden, speziell das Arbeiten mit Entwürfen, vorgestellt und für den Einsatz in transdisziplinärer Forschung vorgeschlagen werden.

10.3 Design und Designforschung

Die Disziplin des Designs ist durch eine inflationäre Verwendung des Designbegriffs geprägt: *nail design, hair design,* Designermöbel oder Designhotel (Mareis 2014). Diese Verwendungen des Begriffs Design beziehen sich zwar auf einen Gestaltungsaspekt, haben aber mit der Disziplin Design wenig zu tun. Die Etablierung des Berufsfelds Design begann mit der Industriellen Revolution und der maschinellen Herstellung von Produkten in Fabriken. Damals hatte sich die Produktgestaltung von der handwerklichen Herstellung gelöst und wurde vom/von der DesignerIn übernommen. DesignerInnen arbeiten seither stets an der Schnittstelle zu anderen Berufsfeldern, die am Produktionsprozess beteiligt sind, wie dem Marketing, den Ingenieurwissenschaften, der Konstruktion, dem Vertrieb oder dem Einkauf. Im Laufe der industriellen und technischen Entwicklung hat sich die Designdisziplin ausgehend vom Produktdesign stark aufgefächert und verfügt heute über ein breites Spektrum an Sub-Disziplinen wie Modedesign, Grafikdesign, Kommunikationsdesign, Verpackungsdesign, Transportation Design, Interface Design, Service Design, Interior Design oder Textildesign (Erlhoff und Marshall 2008).

Um sich dem vielfältig konnotierten und oftmals verwirrenden Begriff des Designs anzunähern, sein Vorgehen zu ergründen und seine potenzielle Anwendbarkeit im Kontext transdisziplinärer Forschung zu erschließen, bedarf es einer sicheren und durchgängigen Verwendung des Begriffs Design. Dieser leitet sich aus dem lateinischen *designare* ab und bedeutet „bezeichnen, bestimmen, im Umriß darstellen, nachbilden“ (Pfeifer 2010). Zur Zeit der Industriellen Revolution hat sich der Beruf des/der DesignerIn als ein/e GestalterIn von industriellen Produkten herausgebildet. In Deutschland herrschte bis in die 1960er Jahre der Begriff des/der FormgestalterIn vor. Auch heute noch bestehen im deutschen und englischen Sprachraum unterschiedliche Assoziationen mit dem Begriff Design. Im deutschen Sprachraum wird mit Design häufig ein durch AutorendesignerInnen[6] geprägtes Bild von Styling[7] assoziiert. Um sich nicht auf das Artefakt-basierte oder Styling-basierte Verständnis von Design zu beziehen,

[6]Unter AutorendesignerInnen versteht man Design-Stars, deren Entwürfe stark mit dem Namen der entwerfenden Persönlichkeit verknüpft sind.

[7]Styling ist die oberflächliche Verschönerung eines Produkts am Ende eines Produktentwicklungsprozesses ohne die vorherige Einbeziehung des Designs und zum Zwecke der Absatzsteigerung.

bieten sich im Deutschen die Verben gestalten und entwerfen als Beschreibung der designerischen Handlung an, wobei der Begriff des Gestaltens die Formgebung, also das Ausgestalten des Figürlichen und der Beschaffenheit (Pfeifer 2010), und der Begriff des Entwerfens das planerische Vorhaben bezeichnet. In der Realität werden die Begriffe Design, Gestaltung und Entwurf jedoch nicht trennscharf verwendet. Im englischen Sprachraum subsummieren sich unter dem Begriff *Design* sämtliche gestalterische, planerische und entwerferische Tätigkeiten, verschiedene Fachdisziplinen sowohl der Gestaltung als auch der Ingenieurwissenschaften sowie das gestaltete Objekt an sich. Unterschieden werden lediglich die Substantiv- und die Verb-Form des Begriffs. In Form des Substantivs bezeichnet *Design* verschiedene Fachbereiche und das gestaltete Objekt. In Form des Verbs umfasst *design* ein planendes und entwerferisches Vorgehen, also ein prozessorientiertes Handeln.

Genau dieses planerische Handeln in Form des Entwerfens ist gemeint, wenn von einem erweiterten Designbegriff gesprochen wird. *„Etwas zu designen impliziert den gesamten Prozess der Strategie, Planung, Entwicklung und Produktion. Der erweiterte Designbegriff oszilliert zwischen ‚design doing' und ‚design thinking'",* attestiert die Kunsthistorikerin Claudia Banz (2016, S. 11). Dabei wird sich auf ein Verständnis von Design bezogen, das nicht mehr alleine die gestalteten Artefakte betrachtet, sondern besonders den Entwurfsprozess im Auge hat, der durch die Anwendung verschiedener Designmethoden eine visuelle Dimension erlangt. So beschreibt der Designer Klaus Krippendorff (2013) in seinem Buch „Die semantische Wende – eine neue Grundlage für Design" in einer *„Trajektorie der Artefaktualität"* wie sich Designprobleme aus dem Bereich der Produkte lösen und über Waren, Dienstleistungen und Identitäten, Interfaces, Netzwerke und Projekte bis hin zur Gestaltung von Diskursen erstrecken. Die Praxis des Designs, das Entwerfen zu planen und diesen Plan mit Gestaltungsmethoden zu visualisieren, für andere sichtbar und erfahrbar zu machen, kommt in einem erweiterten Designverständnis nun nicht mehr nur bei der Gestaltung von Produkten, sondern auch in anderen Bereichen zum Einsatz, wie z. B. bei politischen oder sozialen Prozessen. Anette Geiger (2016, S. 63) merkt dazu skeptisch an: *„Das Soziale am neuen Designbegriff besteht also in der weitaus kritischeren Nachfrage, welche Probleme überhaupt ein Recht darauf haben, durch Design gelöst zu werden."*

Ein erweitertes Designverständnis bedeutet also auch, Design vom gestalteten Artefakt mit seinen ästhetischen und funktionalen Ansprüchen, die mit der Gestaltung von Formen einhergehen, zu lösen und es als eine Praxis mit transformativem Potential zu betrachten. Durch ein Ablösen vom Artefakt kann das Entwerfen als Akt des planerischen Handelns, unterstützt durch die Visualisierungskraft

von Gestaltungsmethoden, auch in anderen Kontexten zur Anwendung gebracht werden. Im Verschränken von planerischem Denken und gestalterischem Handeln findet sich die eigentliche Bedeutung des Designs. Wolfgang Jean Stock bringt es in der Beschreibung von Otl Aichers Werk auf den Punkt: *„Design heißt Denken und Machen aufeinander zu beziehen“* (Aicher 2015, S. 11). In diesem erweiterten Verständnis bewegt sich das Design zwischen zwei Polen, welche von Banz (2016) als *design doing* und *design thinking* beschrieben werden. Als *design doing* kann vornehmlich das Machen, also die Praxis des Designs bezeichnet werden, wohingegen das *design thinking* planerisch-denkende Aspekte des Designs umfasst. Wodurch sich das Machen im Design auszeichnet, wird im Folgenden durch die Praxis-Beschreibung der Sub-Disziplin Produktdesign veranschaulicht.

Die Praxis des Produktdesigns[8] ist durch drei wesentliche Merkmale geprägt: Interdisziplinarität, Kundenorientierung und kreative Handwerklichkeit. Als Tätigkeit an der Schnittstelle zu anderen Disziplinen entlang des Produktentwicklungsprozesses umfasst der Beruf neben gestalterischen Aspekten ebenso betriebswirtschaftliche, ingenieurswissenschaftliche und sozialwissenschaftliche Komponenten. Im Rahmen seiner gestalterischen Dienstleistung ist der/die DesignerIn im ständigen Austausch mit den KundInnen bzw. den AuftraggeberInnen. Während die gestalterische Ausbildung noch durch ein hohes Maß an Handwerklichkeit geprägt ist, da das ästhetische Gespür für Formen insbesondere durch das Sehen, Erspüren und Erarbeiten des Materials erlernt wird, wird in der Berufspraxis viel mit digitalen Gestaltungswerkzeugen am Computer gearbeitet. Der Prozess des Gestaltens ändert sich dadurch jedoch nicht und folgt einem meist gleichbleibenden Ablauf von i) Recherche, ii) Analyse, iii) Konzept, iv) Entwurf und v) Umsetzung (Bürdek 2015; Martin und Hanington 2013). Dabei durchlaufen vor allem die Schritte vier iv) und fünf v) mehrere iterative Schleifen, bis die beteiligten AkteurInnen zufrieden sind. Da es sich beim Produktdesign um die Gestaltung von Dingen für Menschen handelt, spielt der/die NutzerIn im Designprozess eine wesentliche Rolle. Dies wird als Ansatz des nutzerzentrierten Designs bezeichnet. Als Disziplin zwischen Wissenschaft, Kunst und Handwerk ist das Design stark geprägt von gesellschaftlichen, politischen sowie sozialen Entwicklungen und gestalterischen Strömungen wie beispielsweise dem Funktionalismusansatz der Moderne. Auch technische Aspekte wie neue Materialentwicklungen oder Herstellungsverfahren beeinflussen die Gestaltung.

[8]Für die weitere Arbeit und charakteristische Beschreibung der Designpraxis und ihrer Methoden wird der Fokus auf das Produktdesign, also die Gestaltung von Konsum- oder Gebrauchsgütern, gelegt.

Durch die ausgeprägte Anwendungsorientierung spielen theoretische Grundlagen in der gestalterischen Praxis eher eine untergeordnete Rolle. Eine gezielte Auseinandersetzung mit Designmethoden und ihren methodologischen und theoretischen Grundlagen begann jedoch bereits in der 1960er Jahren mit dem ‚design methods movement' und der Ulmer Schule (Mareis 2014). Seither bilden die Semiotik (Theorie der Zeichen) und die Produktsemantik (Lehre von der Selbsterklärung der Dinge) (Krippendorff 2013) wichtige Bausteine im theoretischen Fundament des Designs. Mit der Bologna-Reform und der Einführung eines dritten Ausbildungsschrittes auch für gestalterische Studiengänge beschäftigt sich die Disziplin wieder verstärkt mit den methodisch-wissenschaftlichen Aspekten des Designs. In jüngster Zeit drehen sich Fragestellungen der Designforschung besonders um das Entwerfen als Kulturtechnik und die Bedeutung des Designs im Kontext einer Modus 2-Wissensproduktion (Mareis 2014). Bis heute ist sich das Design jedoch selbst über seinen Status als wissenschaftliche Disziplin uneinig und diskutiert die Bedeutung von Theorien und die Verwendung eigener Methoden kontrovers als Gegenstück der Praxisausrichtung von Design (Romero-Tejedor und Jonas 2010). Der prekäre Status als wissenschaftliche Disziplin spiegelt sich auch darin wider, dass das Design in der Fächersystematik der Deutschen Forschungsgemeinschaft (DFG 2016) in keiner Rubrik aufgeführt wird.

Es ist hilfreich, den Begriff der Designforschung von der Designpraxis und -theorie zu unterscheiden. Als Designpraxis werden alle gestalterischen und entwerferischen Tätigkeiten des Designs bezeichnet. Unter dem Begriff der Designtheorie subsumieren sich alle theoretischen Grundlagen und Konzepte des Designs, wie z. B. Semiotik, Semantik oder Ästhetik. Als Designforschung gelten jene praktisch wissenschaftlichen Tätigkeiten, die sich mit der erkenntnisgenerierenden Perspektive von Designtheorie und -praxis beschäftigen. Das Verständnis von Designforschung, das diesem Beitrag zugrunde liegt, basiert auf dem Konzept des *Research through Design,* das ursprünglich von Christopher Frayling (1993) erdacht und später von Alain Findeli (1998) und Wolfgang Jonas (2012) weiterentwickelt wurde. Fraylings originäre Unterscheidung gliedert sich nach *research into, for* und *through design,* also Forschung *im, für* und *durch* Design. Jonas entwickelt diesen Dreiklang weiter zu einem *research about, for* und *through design,* also einer Forschung über, für und durch Design. Forschung über Design bezeichnet einen Modus des von außen auf das Design Blickens, wie es beispielsweise in der Designgeschichte erfolgt. Forschung für Design beinhaltet Erkenntnisbereiche, die dem Designprozess dienlich sind, wie Marktforschung oder NutzerInnenbeobachtungen. Forschung durch Design bezeichnet ein Konzept, welches Forschung durch die Anwendung oder den Einsatz von entwerferischen Methoden vollzieht. Dabei ist der/die DesignforscherIn direkt in den

Forschungsprozess involviert und nimmt eine aktiv gestaltende Rolle ein. Das Bild der Designforschung als einer Forschung durch Design, gekoppelt mit dem erweiterten Verständnis von Design als einer entwerferischen Tätigkeit, dient als Grundlage für die weiteren Ausführungen in diesem Beitrag.

10.4 Verbindende Elemente der transdisziplinären Forschung und der Designforschung

Sowohl die transdisziplinäre Forschung als auch das Konzept der Forschung *durch* Design können als Modi eines neuen Forschungsverständnisses und der Erkenntnisproduktion angesehen werden, die sich in einigen Punkten ähneln. Basierend auf der Verortung der Felder des Designs und der transdisziplinären Forschung, ihrer theoretischen Konzeption und ihrer methodischen Charakteristika werden die Berührungspunkte im Folgenden identifiziert und genauer beleuchtet.

Ein gemeinsamer Bezugspunkt beider Felder ist das von Gibbons et al. (1994) eingeführte ‚Modus 2'-Wissenschaftsverständnis, das sich vom ‚Modus 1', also dem traditionellen akademischen Modus der Wissenserzeugung durch fünf Charakteristika unterscheidet: die Erzeugung von Wissen im Kontext seiner Anwendung, die transdisziplinäre Form der Forschung, die größere Vielfalt der Wissensformen, die im Forschungsprozess zur Anwendung kommen, die Reflexivität im Erzeugungsprozess sowie neue Maßstäbe zur Beurteilung der Qualität des erzeugten Wissens (Nowotny et al. 2003). Claudia Mareis (2010) identifiziert drei Kriterien, warum die Designforschung idealtypisch für eine „Modus 2"-Wissenserzeugung ist. Dazu zählen für sie deren Anwendungsorientierung und „Praxisnähe", die „interdisziplinäre Ausrichtung" und der „prekäre akademische Status" der Designforschung. Julie Thompson Klein (2014) verankert den ‚Modus 2'-Bezug im Diskurs der Transgression in der transdisziplinären Forschung. Er drücke sich insbesondere durch demokratische Beteiligung verschiedener AkteurInnen an Problemlösungsprozessen und durch das Konzept der Herstellung sozial robusten Wissens aus (Klein 2014), welches ein Wissen bezeichnet, das in der gesellschaftlichen Realität einen längerfristigen Bestand hat.

Beide Forschungsmodi sind zudem geprägt durch eine starke Orientierung an Prozessen, die in iterativen Schleifen durchlaufen werden. So überträgt Wolfgang Jonas (2006) die kleineren Designprozessschritte von Recherche, Analyse, Konzept, Entwurf und Umsetzung (er selbst spricht von Forschung, Analyse,

Synthese und Realisation) in einen größeren Makro-Zyklus der Wissensdomänen Analyse, Projektion und Synthese, der wiederkehrend durchlaufen wird. Im ‚Design Thinking', einer an der Universität Stanford entwickelten Innovationsmethode, die sich am Denkprozess des Designs orientiert, werden die verschiedenen Prozessschritte aus Verstehen, Beobachten, Sichtweise definieren, Ideen finden, Prototypen entwickeln und Testen immer wieder durchlaufen (Meinel et al. 2015). Im idealtypischen Modell eines transdisziplinären Prozesses (Jahn et al. 2012; Lang et al. 2012) sind ebenfalls verschiedene Prozessphasen zu finden. Die Schritte der Problemkonstitution, Wissens-Ko-Produktion und Wissens-Re-Integration werden darin in Phasen unterschieden, die ebenso in rekursiven Prozessen durchlaufen werden. Der zirkuläre Charakter beider Forschungsmodi hat zur Folge, dass die Ergebnisse der Problembearbeitung sowohl in entwerferischen wie auch in transdisziplinären Prozessen jeweils die Bedingungen für die nächste Prozessschleife verändern. Sie verfügen somit beide über ein transformatives Moment. Das idealtypische Prozessmodell der transdisziplinären Forschung, wie es von Jahn entwickelt wurde (Jahn 2008; Jahn et al. 2012), wie auch die verschiedenen Prozessmodelle der Designforschung zeigen, wie stark beide Felder in einem pragmatischen Denken von Problem und Lösung verankert sind. Dies mag auf eine allzu simplifizierende Wissenschaftslogik hindeuten, welcher jedoch an dieser Stelle nicht weiter nachgegangen werden kann. Stattdessen kann die Tatsache, dass beide Felder sich auf das Konzept der *wicked problems* des Planungstheoretikers Horst Rittel (Rittel und Webber 1992) beziehen, als weitere Gemeinsamkeit und Problemorientierung beider Felder gedeutet werden. Rittel, der Anfang der 1960er Jahren an der Ulmer Hochschule für Gestaltung Designmethodologie lehrte, beschreibt diese *wicked problems* (z. Dt. bösartige, vertrackte Probleme), unter die häufig große gesellschaftliche Probleme fallen, als schwer zu lösende Probleme, da sie sich nicht vollständig definieren lassen und ihre Entstehungsbedingungen immer unvollständig sind und sich kontinuierlich ändern (Rittel und Webber 1992). Beide Felder, Designforschung und transdisziplinäre Forschung, bezeichnen die Probleme, die sie bearbeiten als vertrackt in einem Rittelschen Sinne (Buchanan 1992; Klein 2014).

Die Bezugnahme beider Forschungsmodi auf die Bearbeitung vertrackter Probleme mag außerdem der Grund für drei weitere Gemeinsamkeiten von transdisziplinärer Forschung und Designforschung sein. Als erster Punkt ist der Umgang mit Unsicherheit zu nennen, zumal sich die Problemlage und ihre Einflussfaktoren bei der Bearbeitung von *wicked problems* nie vollständig erfassen lassen. Deshalb sind ForscherInnen beider Bereiche dazu gezwungen, sich in einem

unsicheren und unbestimmten Terrain zurechtzufinden und zu behaupten. Diese Bedingungen erfordern neue Methoden und Kompetenzen von ForscherInnen, wie das Anerkennen, dass ein Ergebnis oder ein Entwurf immer nur als vorläufig in einer iterativen Entwicklungsschleife angesehen werden kann. Um der Unsicherheit bei der Bearbeitung von *wicked problems* zu begegnen, beziehen die Designforschung und die transdisziplinäre Forschung als zweite Gemeinsamkeit ganz unterschiedliche Wissensbestände, insbesondere aus nicht-wissenschaftlicher Praxis in den Problemlösungsprozess mit ein. Begriffe wie Partizipation, Co-Design, Co-Produktion und wechselseitiges Lernen kennzeichnen dieses Vorgehen. Die dritte Konsequenz aus der Bearbeitung von *wicked problems* und somit eine weitere damit einhergehende Gemeinsamkeit beider Felder ist die Kontextbezogenheit der dabei entstehenden Forschung. Der spezifische Charakter dieser Form von Problemen und ihre Bearbeitung machen den Design- und transdisziplinären Forschungsprozess sowie die daraus resultierenden Ergebnisse hochgradig singulär.

10.5 Charakteristika der Methoden des Designs

Ein einheitliches Methodenverständnis im Design zu destillieren gestaltet sich schwierig, da es nicht die eine Designdisziplin gibt und sie außerdem fortwährend zwischen Theorie und Praxis oszilliert. Aufgrund der Interdisziplinarität des Feldes werden im Design eine Vielzahl von Methoden verwendet, die auch in anderen Fächern und Disziplinen zum Einsatz kommen und somit nicht designspezifisch sind. Vergleicht man verschiedene Zusammenstellungen von Designmethoden, so sind diese entweder entlang verschiedener Meta-Prozessschritte oder entlang konkreter Design-Aufgaben strukturiert. Jonas et al. (2010) berufen sich in ihrem Methoden-Tool „MAPS“ auf die Meta-Prozessschritte Analyse, Projektion und Synthese, die sie gleichzeitig auch als Domänen des Wissens verstehen (Chow und Jonas 2010). Der Schritt Analyse umfasst darin ein Verstehen des Ist-Zustands; der Schritt der Projektion beschreibt das Antizipieren eines zukünftigen Ideal-Zustands und der Schritt der Synthese beinhaltet das Überführen beider Zustände in ein realistisches Morgen. Andere AutorInnen ordnen Designmethoden entlang bestimmter Aufgaben wie Kreation, Ideenfindung, Darstellung oder Entscheidung an (vgl. Martin und Hanington 2013; Milton und Rodgers 2013), wobei auch diese innerhalb einer Designprozesslogik gedacht sind. Im Kontext der Sub-Disziplinen des Designs finden sich ebenfalls Zuordnungen von Methoden zu einzelnen Designphasen. Am Beispiel des Produktdesigns

soll dies exemplarisch[9] für einen Designprozess bestehend aus den Phasen[10] i) Recherche, ii) Analyse, iii) Konzept, iv) Entwurf und v) Umsetzung unterlegt werden.

Die **Recherchephase** beschreibt die Phase der Informationsbeschaffung rund um den Kosmos des zu gestaltenden Produkts. Dazu zählen beispielsweise Trends in den Bereichen Farbe, Material, Technologieentwicklungen oder auch Lebensweisen (van Boeijen und Daalhuizen 2010). Des Weiteren gilt es sich das Marktumfeld des Produktes anzusehen und beispielsweise herauszufinden, welche MitbewerberInnen sich auf dem anvisierten Feld bewegen, welches Produktportfolio diese zu welchem Preis anbieten und welche weiteren Dienstleistungen um das Produkt existieren. Weitere eingesetzte Methoden in der Recherchephase haben den/die zukünftige/n NutzerIn im Fokus: durch NutzerInnenbefragungen oder verschiedene Formen der NutzerInnenbeobachtung sollen Einstellungen des/der KonsumentIn zum Produkt ergründet oder sein/ihr Umgang mit diesem dokumentiert werden (Rogers und Milton 2011). Die hier beschriebenen Methoden in der Recherchephase wurden originär in den Wirtschaftswissenschaften und der ethnografischen Sozialforschung entwickelt.

Die **Analysephase** umfasst einerseits die eingehendere Auswertung der in der Recherchephase gesammelten Informationen beispielsweise durch die Ergründung der potentiellen Zielgruppe oder die Ermittlung der Stärken und Schwächen des Produkts (SWOT-Analyse). Andererseits umfasst diese Phase auch die detaillierte technische Auseinandersetzung mit dem zu entwickelnden Produkt. So wird beispielsweise mit den aus den Ingenieurswissenschaften stammenden Methoden der Bauteil-, Funktions-, und Prozessanalyse das zu gestaltende Produkt in seine grundlegenden Bauteile zerlegt und ergründet, welche Funktionen das Gesamtsystem und seine einzelnen Bauteile erfüllen (van Boeijen und Daalhuizen 2010; Cross 2000), und welche Prozessschritte bei der Bedienung des Produktes durchlaufen werden. Auf diese Weise kann ein komplexes

[9]Die hier genannten Methoden erheben keinen Anspruch auf Vollständigkeit, sondern dienen lediglich der beispielhaften Beschreibung von möglichen Methoden, die in einem Designprozess zum Einsatz kommen können.

[10]Im Kontext der Designpraxis, des ‚Design Thinkings' und der Designforschung herrscht eine Vielzahl unterschiedlicher Designprozess-Modelle mit teils unterschiedlichen, teils ähnlichen Prozessschritt-Bezeichnungen vor. Zum Zwecke des Überblicks soll der Designprozess deshalb auf die hier vorgestellten fünf Schritte kondensiert werden. Die Phasen sind nicht als trennscharf voneinander abgegrenzt und in einer linearen Logik zu denken, sondern überschneiden sich, gehen fließend ineinander über und wiederholen sich zum Teil.

technisches Produkt in kleinere und einfacher zu erschließende Komponenten unterteilt und können für diese neue Lösungen erdacht werden. Anschaulich lässt sich dies am Beispiel eines Wasserkochers erklären, dessen Gesamtfunktion darin besteht Wasser durch Strom (Input) auf eine bestimmte Temperatur (Output) zu erhitzen. Der Wasserkocher lässt sich in die Bestandteile Wasservolumen, Deckel, Griff, Stromanschluss, Heizelement, Füllstandanzeige und Temperaturanzeige gliedern. Bei der Benutzung des Wasserkochers werden im Groben die Schritte Befüllen, Anschließen, Anschalten, Kochen und Entleeren vollzogen. Sowohl die Analyse der einzelnen Bauteile mit ihren Funktionen als auch das Nachvollziehen der durchlaufenen Nutzungsschritte bieten dem/der DesignerIn zusammen mit den weiteren gewonnenen Einsichten aus der Recherchephase erste Ansatzpunkte für die Gestaltung des Produktes.

Dies mündet in die **Konzeptphase** des Designprozesses, in der Erkenntnisse sich zu ersten Ideen und Gestaltungsansätzen verdichten, indem man sie gezielt durch Kreativmethoden wie beispielsweise dem ‚Brainstorming' zu Papier bringt (van Boeijen und Daalhuizen 2010; Cross 2000). Häufig werden diese dann in Form von *Moodboards,* Persona-Beschreibungen oder *Storyboards* visualisiert. Unter *Moodboards*[11] versteht man Bild-Collagen meist aus Fotos, Zeichnungen oder Materialien, die der Darstellung der Lebenswelt einer Zielgruppe, von Produktstilen oder Formsprachen dienen, *„als möglichst konsistente visuelle Horizonte"* eine erste Stimmung einfangen und als *„Rahmen"* des späteren Entwurfs dienen können (Bürdek 2015, S. 121). Als Persona bezeichnet man eine auf Beobachtungen, Umfragen und demografischen Daten basierende fiktive Person mit authentischen Eigenschaften, Zielen, Gewohnheiten und Haltungen, die Bürdek (2015, S. 116) als einen „hypothetischen Archetypen möglicher Benutzer" beschreibt. Das Erstellen einer oder mehrerer Personas hilft, BenutzerInnenszenarien darzustellen, zu beobachten und Erkenntnisse darüber zu sammeln, wie ein/e NutzerIn auf ein Produkt, eine Dienstleistung oder eine App reagieren könnte. Das *Storyboard* ist die zeichnerische Visualisierung eines Konzeptes oder einer Designidee (van Boeijen und Daalhuizen 2010). Es ist ähnlich wie ein Comic aus Einzelbildern aufgebaut und dient der Strukturierung, Planung und Darstellung eines Handlungsablaufs. Es wird somit zur Denk- und Planungshilfe, die wie ein roter Faden durch die Handlung führt und alle Gestaltungselemente in sich aufnimmt. Sowohl das *Storyboard* als auch *Moodboards* und Persona-Beschreibungen dienen als Kommunikationsmittel von Ideen gegenüber KollegInnen und KundInnen.

[11]Manchmal auch *Mood-Charts* genannt.

Auch in der **Entwurfsphase,** die das eigentliche zu Papier bringen der Ideen umfasst, wird visuell gearbeitet. Dies schlägt sich in analogen Skizzen[12] der ganzen Produktidee, ihrer Form oder einzelnen Aspekten wie bestimmter Funktionen, Materialien oder Mechanismen nieder. Skizzen werden in unterschiedlichen Detaillierungsgraden angefertigt – von der groben Linienführung einer Form bis hin zu realitätsnahen Produktdarstellungen einschließlich der verwendeten Materialien (van Boeijen und Daalhuizen 2010; Parsons 2009). Weiterhin wird insbesondere im Produktdesign auch dreidimensional entworfen – die Palette erstreckt sich vom Anfertigen einfacher Modelle der sogenannten *Mockups,* über die unterschiedlichen Detaillierungsgrade des *Prototypings* bis hin zum professionellen Modellbau in der Spätphase des Designprozesses (van Boeijen und Daalhuizen 2010; Hallgrimsson 2012; Parsons 2009). Parallel zum analogen Zeichnen und Bauen werden am Computer erste sogenannte „CAD-Scribbles" angefertigt. Dabei handelt es sich um dreidimensionale Konstruktionszeichnungen, die mithilfe eines CAD-Programmes erstellt werden und anhand derer sich Größenverhältnisse oder bestimmte technische Funktionen detaillierter darstellen und überprüfen lassen. Alle Methoden der Entwurfsphase dienen dem Erarbeiten, Reflektieren und Überarbeiten von Ideen und bilden die Basis für Diskussion, Entscheidung und Umsetzung eines bestimmten Entwurfs.

In der **Umsetzungsphase** wird der Entwurf in das konkrete Design überführt und mit allen Details des finalen Produkts versehen. Dazu werden die endgültigen CAD-Daten erstellt – je nach Komplexität des Produkts wird dieser Schritt von KonstrukteurInnen übernommen – und technische Zeichnungen angefertigt (Parsons 2009). Die CAD-Daten dienen ebenfalls als Grundlage für die Herstellung von Designmodellen oder Funktions-Prototypen[13] mittels 3D-Druck-Verfahren[14] und den vom Computer errechneten fotorealistischen Darstellungen, sogenannten *Renderings. Renderings* werden häufig dann eingesetzt, wenn das fertige Produkt in seiner realistischen Umgebung gezeigt werden soll, dieses aber noch nicht verfügbar ist.

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[12]Manchmal auch *Scribbles* genannt.

[13]Der Unterschied zwischen Designmodellen und Funktions-Prototypen besteht darin, dass Designmodelle nur das realistische Aussehen eines Produktes wiedergeben, nicht jedoch wie bei einem Funktions-Prototyp bereits im Gebrauch funktionieren.

[14]Dies ist ein Sammelbegriff für verschiedene Verfahren, bei denen durch das schichtweise Aufbringen eines Materials, zum Beispiel Kunststoff, Gips oder Metall, nach und nach eine dreidimensionale Form entsteht. Je nach Qualität des Verfahrens und Materials können diese Formen mit einer entsprechenden Lackierung als Designmodell oder bereits als Funktions-Prototyp verwendet werden.

Während das Design in den Phasen Recherche, Analyse, Konzept und Umsetzung auch aus dem Methodenkanon anderer wissenschaftlicher Disziplinen schöpft, können die Entwurfsmethoden als spezifisch für das Design und andere gestaltende Disziplinen bezeichnet werden. Wobei dies nicht nur das Design und seine Sub-Disziplinen einschließt, sondern auch Fächer wie Architektur oder Ingenieurswissenschaften, in denen Entwurfsmethoden zum Einsatz kommen. Für die vorliegende Arbeit werden ausschließlich Entwurfsmethoden herangezogen und begrifflich von den Designmethoden getrennt. Als Designmethoden werden alle Methoden entlang eines Designprozesses bezeichnet, wohingegen Entwurfsmethoden speziell gestaltungsspezifische Herangehensweisen, die sowohl zwei- als auch dreidimensionale Artefakte einbeziehen, umfassen. Diese Unterscheidung ist deshalb dienlich, da sie den Entwurf nicht als einen Schritt auf dem Weg zu einem Design hin denkt, sondern das Entwerfen als eigenständige spezifische Praxis betrachtet. Dadurch lässt sich das Entwerfen vom Gestaltungskontext lösen, auf seinen integrierenden und intervenierenden Charakter hin überprüfen und somit zielgerichteter in anderen Anwendungskontexten wie der transdisziplinären Forschung zum Einsatz bringen. Im folgenden Abschnitt wird deshalb ein Konzept verschiedener Integrationsdimensionen (Jahn et al. 2012) aus den transdisziplinären Nachhaltigkeitswissenschaften herangezogen und eine Entwurfsmethode daran exemplarisch auf ihre Integrations- und Interventionsleistung hin untersucht.

10.6 Entwurfsbasierte Intervention und Integration

Vor der Analyse des intervenierenden und integrierenden Charakters von Entwurfsmethoden gilt es beide Begriffe zu bestimmen und voneinander zu unterscheiden. Laut etymologischem Wörterbuch stammt der Begriff der Intervention vom Lateinischen *intervenire* ab und bezeichnet ein „vermittelndes Eingreifen“ (Pfeifer 2010). Dabei ist insbesondere der vermittelnde Aspekt des begreifbar Machens im Designkontext von Interesse. Bei der Arbeit mit Entwürfen ist dies im wahrsten Sinne des Wortes als ein Be-Greifen zu verstehen. Der Begriff der Integration wird als ein „Einbeziehen“ und „Eingliedern“ verstanden (Pfeifer 2010). Die vermittelnden und eingliedernden Eigenschaften von Entwurfsmethoden im Kontext transdisziplinärer Forschung lassen sich vor dem Hintergrund der von Jahn et al. (2012) eingeführten Integrationsdimensionen untersuchen. Diese gliedern sich in epistemische, sozial-organisationale und kommunikative Integration. Vor dem Hintergrund der strukturierenden Funktion der Integrationsdimensionen im Kontext dieser Arbeit wird dem Begriff

der Integration der Vorrang gegeben, wenngleich die transdisziplinäre Praxis im Sinne des oben beschriebenen Verständnisses ein partizipatives Element durch die Einbindung verschiedenster AkteurInnen aufweist. Anhand der Integrationsdimensionen soll eine ausgewählte Entwurfsmethode – das *Prototyping* – exemplarisch in ihrem Einsatz in einem transdisziplinären Bezugsrahmen beschrieben und auf ihre integrierenden und intervenierenden Eigenschaften hin analysiert werden. Besonders die Dreidimensionalität der entstehenden Entwürfe in einem *Prototyping*-Prozess sprechen für dessen Auswahl aus der Vielzahl verschiedener Entwurfsmethoden. Die Ergebnisse lassen eine Verortung und Bewegung im Raum zu und ermöglichen zudem die Betrachtung aus verschiedenen Perspektiven. Weiterhin lassen sich *Prototyping*-Prozesse sowohl allein als auch in der Gruppe durchführen, die Elemente können dekonstruiert und neu arrangiert werden, an ihnen kann diskutiert und gemeinsam gebaut werden. Gerade die haptische Qualität macht sie für die Integrationsarbeit und Erkenntnisgenese relevant.

Als *Prototyping* wird das Bauen kleiner Entwürfe bezeichnet, die sich in ihrem Entwicklungsstadium zwischen *Mock-up* und Prototyp befinden (Hallgrimsson 2012). *Mock-ups* sind kleine Modelle aus preiswerten Materialien und dienen der Überprüfung eines Designs, indem sie den ersten Schritt von der Skizze zur dreidimensionalen, greifbaren Form vollziehen. Ziel des *Mock-ups* ist die schnelle Visualisierung des Entwurfs bzw. die Überprüfung verschiedener wichtiger Funktionen, z. B. Proportionen, äußere Form, Ergonomie oder technische Mechaniken. Dazu kann der ganze Entwurf oder nur Teile gebaut werden. *Mock-ups* sind ein Kommunikations- und Diskussionsmedium und können in Besprechungen zwischen NutzerInnen und DesignerInnen oder im Design-Team verändert und weiterentwickelt werden. Eine Stufe weiter in ihrer Entwicklung sind Prototypen. Diese werden je nach ihrem Detailgrad in Designprototyp (Konzeptmodell zur Überprüfung ästhetischer und ergonomischer Merkmale), geometrischer Prototyp (maßstabsgetreues Modell zur Überprüfung des Gebrauchs), Funktionsprototyp (Funktionsmuster mit Eigenschaften des späteren Serienmodells) und technischer Prototyp (nahe am Endprodukt) unterschieden (Moeller 2008). Beim *Prototyping* kommen verschiedene preisgünstige Materialien wie Papier, Pappe, Plastik oder Dinge aus dem Haushalt wie Schwämme, Folien oder Holzspieße zum Einsatz. Aus diesen setzt die entwerfende Person allein oder gemeinsam mit anderen aus dem Team die Idee oder einen bestimmten Aspekt der Idee in kurzer Zeit dreidimensional um. Grundsätzlich kann das *Prototyping* von jeder Person ohne bestimmte fachliche Kenntnisse und besondere Fertigkeiten durchgeführt werden. Dabei sind alle Materialien und jede *Prototyping*-Technik erlaubt. Die entstandenen Entwürfe müssen keinen ästhetischen oder funktionalen Ansprüchen gerecht werden, sondern sollen vielmehr der Reflexion, Überprüfung, Visualisierung und Kommunikation einer Idee dienen.

Am Beispiel eines Fallstudien-Workshops in Transsylvanien, der im Rahmen des Forschungsprojektes ‚Leverage Points for Sustainability Transformation' durchgeführt wurde, wird veranschaulicht, wie die Entwurfsmethode *Prototyping* im Kontext eines transdisziplinären Forschungsprozesses zum Einsatz gebracht werden kann. Ziel der transdisziplinären Fallstudie im Süden Transsylvaniens ist es, nachhaltige Transformationsprozesse in der Region zu ermöglichen und zu unterstützen. Die Basis dieser Arbeit bildet ein in einem vorangegangenen Projekt partizipativ erstelltes Zukunftsszenario für die Region im Jahr 2043. Im Rahmen des Workshops im September 2016, an dem 30 AkteurInnen aus der Region teilgenommen haben, sollten die bestehenden Nachhaltigkeitsinitiativen und ihr Beitrag zur Zukunftsvision identifiziert und erste Ideen für die Zusammenarbeit der verschiedenen Initiativen entwickelt werden. Für diese Aufgabe kam das *Prototyping* in zwei Phasen zum Einsatz: In einer individuellen *Prototyping*-Phase wurden die einzelnen AkteurInnen gebeten, als VertreterInnen ihrer Initiative ihren bereits bestehenden Beitrag für die nachhaltige Zukunftsvision zu reflektieren und mit dem vorhandenen Material zu bauen (Abb. 10.1). Die dabei entstandenen Prototypen wurden anschließend den anderen Mitgliedern der Kleingruppe vorgestellt und erklärt. In einem zweiten Schritt wurden die TeilnehmerInnen aufgefordert auf Basis ihrer individuellen Beiträge ein gemeinsames Vorgehen zu diskutieren und dieses ebenfalls mit den Materialien und den vorhandenen Prototypen zu bauen (Abb. 10.2).

Abb. 10.1 Beispiel eines Entwurfs, der den individuellen Beitrag einer Initiative veranschaulicht

Abb. 10.2 Die TeilnehmerInnen diskutieren anhand des Materials und der individuell erstellten Entwürfe ein gemeinsames Vorgehen ihrer verschiedenen Initiativen

Betrachtet man das *Prototyping* auf der Ebene der epistemischen Integration, so lässt sich beobachten, dass die TeilnehmerInnen in einem reflexiven Prozess eigene und fremde Gedanken am Entwurf verhandeln. Ideen oder, wie im Beispiel der Fallstudie, Initiativen einer Organisation werden im individuellen und kollaborativen Bauprozess visualisiert. Das Material lädt die TeilnehmerInnen dazu ein, Gedanken in material- und objektbezogene Metaphern zu übersetzen. Dadurch kann dahinterliegendes Wissen thematisiert und versprachlicht, aber ebenso sprach- und textalternativ dargestellt werden. Durch das Zurückwerfen auf die wenig genutzte und etablierte Ausdrucksform des dreidimensionalen Darstellens begeben sich die AkteurInnen mit verschiedenen fachlichen Hintergründen und unterschiedlichen Hierarchiestufen auf eine ähnliche Stufe des Könnens. Bestehende Unterschiede, die in heterogenen Teams zutage treten, werden ausgeglichen. Die im *Prototyping* entstandenen Entwürfe dienen dem Austausch, der Mitteilung und Diskussion eigener Gedanken mit anderen. Die Kommunikation zwischen den am Prozess beteiligten TeilnehmerInnen kann vermittelt über den Entwurf erfolgen. Dabei werden potentielle sprachliche Unterschiede durch die Einbeziehung der visuellen Dimension nivelliert und sorgen damit auf der Ebene der Kommunikation für eine stärkere Integration. In diesem Beispiel wurden ebenso Aspekte der sozial-organisationalen Integration adressiert, da die TeilnehmerInnen als VertreterInnen ihrer Organisation bestehende Aktivitäten visualisierten, sich über unterschiedliche Interessen austauschten und in einem zweiten Schritt gemeinsam nach verbindenden Elementen und Synergien suchten.

Als erste Beobachtung aus der Arbeit mit Entwürfen innerhalb transdisziplinärer Prozesse lässt sich zusammenfassen, dass die Integrationsdimensionen (Jahn et al. 2012) als Instrumente der Analyse und Planung von Integration sehr dienlich sind. Im konkreten Moment der praktischen Arbeit haben die Entwürfe eine stark verbindende Wirkung, sodass sich in der Praxis die verschiedenen Dimensionen von Integration kaum voneinander trennen lassen. Von den TeilnehmerInnen wird die prototypische Arbeit mit Entwürfen disziplin- und praxisübergreifend sehr gut aufgenommen und als positiv für den kommunikativen Austausch und die gemeinsame Arbeit bewertet. Es konnte beobachtet werden, dass AkteurInnen ins Gespräch kommen, die sonst eher nicht miteinander sprechen. Vereinzelt wurde eine gewisse Einschränkung durch die Wahl der Ausdrucksmittel angemerkt.

Der methodische Einsatz von *Prototyping* im Kontext transdisziplinärer Forschung hat explizit vermittelnden und integrativen Charakter, da alle AkteurInnen gleichberechtigt individuell und kollaborativ in den Entwurfsprozess eingebunden sind. Eigene und fremde Perspektiven werden vermittelt und im Kontext der Anwendung von Entwürfen begreifbar gemacht. Genau dieses vermittelnde Eingreifen in den transdisziplinären Prozess beschreibt den interventionistischen Charakter eines Entwurfs, der auf allen Ebenen der Integration zum Tragen kommt. Grundsätzlich kann der Einsatz von Design bezogen auf Interventionen auf zwei Ebenen gedacht werden: einerseits als *Design von Intervention,* was einem Gestalten von Interventionen und somit eher einer Dienstleistung durch das Design entspräche. Andererseits als *Design als Intervention,* was eine allumfassende Qualität hätte und implizieren würde, dass jegliche gestalterische Tätigkeit von interventionistischem Charakter sei. Im Sinne der oben ausgeführten Erläuterungen zu einem erweiterten Designbegriff und dem vorliegenden Verständnis von Designforschung wird hier eine dritte Kategorie der *entwurfsbasierten Intervention durch Design* vorgeschlagen. Diese Wendung betont die Eigenständigkeit des Entwurfsprozesses und bewahrt den Interventionsbegriff vor zu starker Vereinnahmung durch das Design.

Der vorgestellte Einsatz entwurfsbasierter Methoden, im konkreten Fall des *Prototypings,* erweitert das methodische Repertoire transdisziplinärer Forschung. Als Ergänzung zu Sprache und Text überbrücken Entwürfe, eingesetzt in der Zusammenarbeit heterogener Teams, unterschiedliche kommunikative Fähigkeiten, epistemische Kulturen, Sprachen und methodische Praxen. Folglich erleichtern sie die epistemische, kommunikative und sozial-organisatorische Integration der beteiligten AkteurInnen und tragen aktiv zur Entwicklung partizipativ erzeugter Lösungen und der Ko-Produktion von sozial-robustem Wissen bei, welches in den Nachhaltigkeitswissenschaften benötigt wird.

10.7 Resümee

Der vorliegende Beitrag hat einen ersten Einblick in die Praxis der entwurfsbasierten Intervention im Kontext transdisziplinärer Forschung gewährt und gezeigt, wie durch die Arbeit mit Entwürfen Momente der Integration erzeugt werden können. Dabei wurde ausgelotet, wie Entwurfspraktiken, die in Designprozessen zur Anwendung kommen, in transdisziplinärer Forschung fruchtbar gemacht werden können. Nach einer Positionierung und Charakterisierung des Designs und der Designforschung sowie deren gängigen Methoden wurden Gemeinsamkeiten zwischen der Designforschung und der transdisziplinären Forschung ausgelotet, um den Transfer von Entwurfspraktiken zur Unterstützung von Integrationsprozessen in transdisziplinären Teams zu rahmen. Wir haben uns dabei an der Unterscheidung von epistemischen, sozial-organisatorischen und kommunikativen Dimensionen orientiert und analysiert, inwiefern diese unterschiedlichen Dimensionen von Integration mittels Entwurfspraktiken adressiert werden können. Dabei hat sich gezeigt, dass das Entwerfen in allen Integrationsdimensionen Wirksamkeit entfalten kann und als entwurfsbasierte Intervention die verschiedenen Integrationsdimensionen verschränkt und aufeinander bezogen werden können. Eine Erweiterung des Integrationsdreiklangs um die kulturelle Dimension wird allerdings als wichtig erachtet, zumal sich im Arbeiten in heterogenen Teams sowohl wissens- und erkenntniskulturelle Differenzen wie auch kulturelle Differenzen in unterschiedlichen Praktiken zur Geltung bringen, die in Integrationsprozessen explizit adressiert werden sollten.

Im Vergleich zu anderen Methoden, die in transdisziplinären Forschungsprozessen zum Einsatz kommen, verfügen Entwürfe über spezifische Qualitäten, die sich einerseits durch den ihnen innewohnenden Prozesscharakter und andererseits ihren Objektstatus auszeichnen. Sie sind gleichzeitig im Werden und vollendet. Die Visualität, Tangibilität und räumliche Verortbarkeit von Entwürfen ermöglicht es, unterschiedliche Perspektiven an ihnen zu verhandeln. Als materielle Form des Ausdrucks ergänzen sie Sprache und Text und verfügen über eine ganz eigene metaphorische Qualität. Als Werkzeuge erfüllen Entwürfe noch weitere Funktionen: durch sie und mit ihnen lässt sich ein Gedanke entwickeln; Ideen können an ihnen reflektiert werden; sie ermöglichen das Gewinnen von Erkenntnis; durch sie können Ideen kommuniziert werden; mit ihnen können Visionen erarbeitet werden und anhand verschiedener Entwürfe lassen sich Entscheidungen treffen.

Weiterer Forschungsbedarf für den Einsatz entwurfsbasierter Interventionen und ihres Integrationspotenzials sehen wir vor allem in der Analyse empirischer Daten, die den Prozess und die Wirkung des Entwerfens beleuchten sowie in der

Auswertung von Entwürfen selbst. Insbesondere Letzteres stellt methodisch eine große Herausforderung dar, zumal für die Analyse des Artefaktischen ungleich weniger elaborierte Analysemethoden vorliegen als für Text- und Bildanalysen. Dazu bedarf es einer vertiefenden Auseinandersetzung mit den epistemischen Qualitäten von Entwürfen, wie z. B. den Fragen, inwiefern sie selbsterklärend sind oder einer Beschreibung bedürfen; welchen Modellcharakter sie haben; inwiefern sie als Metaphern zu deuten sind und in welcher Form sich Codes in sie einschreiben, die anschließend wieder decodiert werden müssen. Ebenso gilt es den Einsatz weiterer Entwurfsmethoden über das *Prototyping* hinaus zu beleuchten und zu ergründen, in welchen Phasen eines transdisziplinären Prozesses Entwürfe zum Einsatz kommen können und welche Funktion sie dabei erfüllen.

Für die Praxis transdisziplinärer Forschung, aber auch für die Erforschung transdisziplinärer Integrations- und Interventionsprozesse eröffnet sich mit der Entwurfspraxis ein Feld, das den methodischen Kanon des Arbeitens in heterogenen Teams vielversprechend erweitert. Darüber hinaus ermöglicht sie einen alternativen Zugang zum notwendigen und vertieften Verständnis darüber, wie Prozesse der kooperativen und partizipativen Wissens- und Erkenntnisgenerierung vor sich gehen. Mit dem Entwerfen wird ein Ort geschaffen, der diesseits jeder sprachlichen Verfasstheit und abseits vertrauter Forschungspraxis liegt, und der als ein gemeinsamer Ausgangspunkt heterogener Teams gestaltet werden kann.

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Daniela Peukert, ist Produktdesignerin und arbeitet als Designforscherin an der Leuphana Universität Lüneburg. Ihre Arbeits- und Forschungsschwerpunkte liegen in den Bereichen gestalterische Wissensproduktion, Transdisziplinarität und Design von Transformationsprozessen. In ihrer Promotion geht sie den Fragen nach, welche epistemische Qualität gestaltete Artefakte besitzen und wie mit Hilfe von Designmethoden Integration in transdisziplinären Prozessen gefördert werden kann.

Ulli Vilsmaier, forscht und lehrt an der Leuphana Universität Lüneburg. Ihre Forschungs- und Lehrschwerpunkte umfassen epistemologische und methodologische Grundlagen sowie text-, bild- und artefaktbasierte Methoden inter- und transdisziplinärer Forschung. In einer Perspektive responsiver Vernunft beschäftigt sie sich mit der Konstitution von Raum und der Gestaltung von inter- und transdisziplinären Zwischenräumen. Zu den Themenbereichen zählen Nachhaltigkeit und Nachhaltigkeitswissenschaften sowie nachhaltige Stadt- und Regionalentwicklung.

‘By thinking the problematic and having the possibility of an epistemological break, problematic designing allows us to leave the taken path and thus for an open “futurity” to arise.’

11.2. Article 2

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ARTICLE

Designing a Transformative Epistemology of the Problematic: A Perspective for Transdisciplinary Sustainability Research

Esther Meyer and Daniela Peukert

Methodology Center and Faculty of Sustainability, Leuphana University of Lüneburg, Luneburg, Germany

ABSTRACT

This paper elaborates on the question of how to design an epistemological foundation for problem-oriented, collaborative forms of research, such as transdisciplinary sustainability research. It picks up approaches of twentieth-century European philosophy to the concept of the problematic and design research. The problematic is explained as a historical epistemological effort. Design research shows parallels to the epistemological thinking of the problematic by contributing to a differentiation and historicity of knowledge and knowledge production itself. Designing is constituted by a nexus of conceptual thinking and creative making, and so designs are drafts themselves. We interweave the thinking of the problematic with the practice of designing in order to open an epistemological perspective in and for transdisciplinary sustainability research. We call this a 'thinking practice of problematic designing,' which describes an epistemological tool as well as a transformative process. Problematic designing is characterized by always being in the making – its designs can grow beyond their conditions of production. By opening up manifold dimensions of transformation, this epistemological approach is oriented towards complexity, enabling the generation of sound and future-relevant knowledge.

KEYWORDS

Problematic thinking; design research; futurity; complexity

Introduction

> Addressing our growing planetary crisis, and attendant symptoms of human and human-ecological disconnect, requires a profound epistemological reorientation regarding how societal structures are conceived and articulated. (Williams et al. 2017, 41)

With these words, Lewis Williams and his colleagues introduce their ideas on a 'Global De-colonial Praxis of Sustainability.' We follow the requirement of an 'epistemological reorientation' (Williams et al. 2017) as formulated in the quote as well as by other authors (Krohn, Grunwald, and Ukowitz 2017; Nowotny 2006). We revisit the question of how *transdisciplinary research* might be equipped with a *transformative epistemological foundation* to face a planet in crisis mode. Transdisciplinary research forms part of sustainability sciences and is in this setting a form of boundary-crossing research (Vilsmaier 2018),[1] oriented towards goals of sustainability, which has emerged from German-speaking Europe for almost 20 years.[2]

Transdisciplinary sustainability research is often realized in projects that focus on specific problems for which a solution is to be found. We begin by referring to a previous study on the term *problem* in European transdisciplinary sustainability sciences (Meyer forthcoming b).[3] According to

CONTACT Esther Meyer esther.meyer@leuphana.de Methodology Center and Faculty of Sustainability, Leuphana University of Lüneburg, Luneburg, Germany

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the results, the term problem on the one hand derives its meaning from a normative orientation towards problem-solving, and on the other hand analytically relates to the process level of research. By focusing on problem-solving, an instrumental (Welch 2011) controllability (Doucet and Janssens 2011) and manageability of knowledge or the research process is supposed. Furthermore, a problem-solving orientation 'assumes that the world is a problematic that needs to be solved. [. . .] The narrow focus required for this approach deals with problems in isolation, as a 'closed system,' and deals with neither context nor relationships' (Haley 2011, 24). The results of the study further disclose that the term problem has neither been explained theoretically nor connected to epistemological issues in the discourse. At the same time, authors highlight exactly this connection and see a need for an elaboration of epistemological implications in transdisciplinary research (Krohn, Grunwald, and Ukowitz 2017; Nowotny 2006).

Welch traces two discourses in his genealogy of interdisciplinarity: 'the critical and instrumental modes of interdisciplinarity' (Welch 2011, 4) that 'are not mutually exclusive' (Welch 2011, 4). Instead, 'their synthetic relationship is essential for developing an interdisciplinary theory as an emergent epistemological innovation' (Welch 2011, 4).

Therefore, we pick up on the critical, philosophical concept of *the problematic* (Hörl and Leistert 2019; Meyer forthcoming a) that has been constituted in the 'breakdown of traditional epistemological structures' (Welch 2011, 4). We then establish a link to *design*, as a pragmatic and methodology-oriented (Repko and Szostak 2008) product of the instrumental strand, in order to inform transdisciplinary sustainability research. Our goal is to open an epistemological perspective in and for transdisciplinary sustainability research that does not rely on a mechanistic solvability of problems, nor creates epistemic problems to control the future of science. Our thinking is based on the assumption that collaborative research forms in themselves pave the way for science and research in planetary crisis mode, if they are 'navigating transformative TDR [transdisciplinary research] processes in and under fluid social conditions' (Van Breda and Swilling 2019, 826). For this kind of collaboration, however, we do consider the need to unlearn the language of control and set up new alphabets,[4] 'practice theories [. . .] that [. . .] attempt to provide a new vocabulary to describe the world' (Nicolini 2013, 9 in Maguire 2018, 113).

In this paper, we explain the philosophical concept of the *problematic*,[5] which has been developed in a twentieth-century French epistemological tradition. The concept of the problematic emphazises French theory's differentiation of the subject–object dichotomy (Maniglier 2012), which makes it interesting for transdisciplinary research (Nicolescu 2010), where research collectives go beyond the traditional divide of an active researcher and a passive object of research (Vilsmaier, Brandner, and Engbers 2017). Thus, the concept of the problematic contributes to our goal of epistemologically substantiating the discourse. Transdisciplinary sustainability research constitutes a 'profound turn in Western thought' (Welch 2011, 4), and thus carries a historical share of thinking the problematic. Nevertheless, the discourse that we are looking at builds on patterns of separation, such as the distinction of problem and solution (Nicolescu 2010). Subsequently, we propose *designing* as a creative practice that offers a pathway towards a transformative epistemology, in which thinking and doing are strongly interconnected. The reason we bring together the philosophy of the problematic and design lies in the twofold nature of design. On the one hand, design reveals its strong epistemological force in the process of designing drafts as (manifested) ideas. On the other hand, designing as a practice and process produces tangible artefacts that are able to visualize and concretize transformations. By bringing together problematic thinking and design, we use the problematic as a philosophical base and interweave it with design to develop an epistemological approach that is able to unfold intended connections to transformative practice. We condense distinctive characteristics from the examination of the problematic and put them into relation with design to develop the thinking practice of *problematic designing*. By thinking practice, we mean the thinking that influences practice through being informed by practice. The basic idea of problematic designing is to embed the practice of designing in the epistemology of the problematic. We understand the *problematic* in the sense of a designed draft. For us, it 'is the beginning of

a thought process that moves towards a consciousness of a way of being as well as a way of doing in the world which is [...] always a process of becoming' (Maguire 2018, 110) and it 'is more about an attitude to knowledge than it is about knowledge; [...] it is generative not replicative' (Maguire 2018, 114).

Afterwards, we discuss the perspective of problematic designing in relation to transdisciplinary sustainability research with regards to two of its main characteristics (Engbers 2018): heterogeneous actor relationships and solving complex problems. In combining these two characteristics we propose a *transformative epistemology of problematic designing* as a new perspective for transdisciplinary sustainability research, based on epistemological breaks, as an alternative primer to a dilemma of control. In the transformative epistemology of problematic designing we see a possibility of the (re-) politicization, and thus (re-)futurization (Raven and Elahi 2015, 51), of sustainability-related issues.

Problematic designing serves as a thought process as well as a research and design process. In this conceptual paper, we will primarily focus on the thought process – practical implications for transdisciplinary and transformative research and design processes will be addressed in upcoming research.[6]

The Problematic

We reflect upon the problematic as described by French and Belgian philosophers over the last century. For this purpose, authors and concepts are introduced from this philosophical direction in the current chapter. We aim to historically understand the concept of problematic thinking in order to work out the transformative epistemology of problematic designing for transdisciplinary sustainability research. We begin to derive an epistemological problematic from Gaston Bachelard,[7] continue with onto-epistemological stances that we explain through the study of literature on and by Gilbert Simondon,[8] and finally discuss (research)-ethical considerations by Isabelle Stengers.[9]

With Bachelard, the problematic marks an *epistemological break* (Maniglier 2012, 22) in the understanding of a demarcation between subject and object.[10] The problematic can be understood as an 'applied doubt',[11] 'a doubt specified by the object of knowledge' (Bachelard 2012, 30). It is in the sense of a doubt arising from a concrete situation against the background of universal assumptions. This doubt arises always and necessarily[12] and marks the knowledge-generating moment. Through a problematic epistemology everything, including knowledge, is constituted in correlation,[13] as Patrice Maniglier writes: 'Neither objects nor subjects, neither things nor minds, exist primarily; there are only problems, which institute the very possibility of the correlation' (Maniglier 2012, 22). Correlation thus has an epistemological function. Problems as epistemic starting points therefore 'constitute that which makes it important, relevant, critical, to know about' (Maniglier 2012, 21) an object of knowledge. An object is always preceded by an objectification. In the epistemology of the problematic, 'the bases for knowledge are themselves put to the test, and brought into question by the question' (Maniglier 2012, 22) of the frame of knowledge production itself. Bachelard is concerned with the epistemological, as a history of science[14] itself, which for him breaks with ontological fundamentalism. 'It is noteworthy that at a time when others were writing about the unity of science and of the scientific method, Bachelard was talking about the plurality of regional rationalisms' (Tiles 2012, 26). To summarize, the problematic works as a theorization on the mediation between the scientific subject and the object, and on the knowledge-generating moment. For Bachelard, it is a component with which he explains his historical epistemology.

An onto-epistemological stance towards the problematic is expressed by Gilbert Simondon. For him, the problematic is an auxiliary construction in the explanation of *becoming an individual* – what he calls individuation of living beings. Individuation means that the living can only become in relation to its condition (Scott 2014). Individuation takes place in a situated, open process, in which the problematic is also described in a relational sense (Voss 2018). Simondon thus calls it *problematic becoming*, which is characterized by inventing axiomatics. Axiomatics he explains as internal structures that make it possible to live in relation to changing conditions (Voss 2018). '[T]he social dimension of the transindividual' (Voss 2018, 96) arises out of this problematic movement. It forms

both the living individual and their conditions while also being formed by them (Voss 2018, 96). They keep each other moving. Such continuously moving, living structures Simondon calls *milieu* (Voss 2018, 96). Individuation may crystallize in a *metastable* – structurally compatible – state in the 'association of individual and milieu' (Voss 2018, 99; Scott 2014, 4). The problematic has the function of inventing this association into ever new, metastable states, which itself is the function of psychic life (Voss 2018). With regard to problem solving, Simondon writes,

> [t]o solve a problem is to be able to step over it, to be capable of recasting the forms that are given within the problem and in which it consists. The solution of real problems is a vital function presupposing a recurrent mode of action that cannot exist in the machine: the recurrence of the future with respect to the present, of the virtual with respect to the actual. (Simondon 2017, 156)

Simondon adds an unconditional epistemological moment to this rather ontological level of description, which we will have to examine in more detail in this work: Individuation always takes place in particular, concrete cases that need to be explored (Voss 2018) and that marks the knowledge-generating – problematic – moment.

Research-ethical considerations are introduced by Isabelle Stenger's concept of *ecology of practices*, which, as a tool for thinking (Stengers 2005), is connected to problematic thinking. She continues in her concept with the particular, situated and plural thinking that is incompatible with universal or totalitarian epistemologies and problems, believing in the truth (Fichant 1975; Harrasser and Solhdju 2016; Stengers 2005). Regarding the term problem she formulates, 'a problem is always a practical problem, never a universal problem mattering for everybody. Problems of the ecology of practices are also practical problems in this strong sense, that is problems for practitioners' (Stengers 2005, 193). Ethical assessment of research outcomes takes place within an ecology of practices, based on effectiveness, consequences and matter, by those who affect the practice (Harrasser and Solhdju 2016; Stengers 2005), and in a 'specific milieu' (Harrasser and Solhdju 2016, 74, own translation). Practice and surrounding environment condition each other and emerge as milieu-like ecology. Similar to Simondon, the epistemological moment lies in the diagnosis of the 'relationship of relevance' between (Stengers 2005, 185) the material and symbolic relations, with and within the milieu. For Stengers, a milieu is essentially characterized by entanglement between (epistemic) practice, which includes the practitioners, and its effects. The effects become new surroundings for practices (Stengers 2005), in which she sees the ecological moment of a practice. She regards an ecology of practices as good and equivalent to modern modes of cognition (Harrasser and Solhdju 2016) around 'rational universality' (Stengers 2005, 196). An ecology of practices also realizes ethics, in the form of ethical experimentation (Harrasser and Solhdju 2016; Stengers 2010). Practice and surrounding environment condition each other, and emerge as milieu-like ecology – as a moment of ethical knowledge generation (Stengers 2005). Stengers incorporates the structure of the problematic in her ecology of practices as a transformative tool for thinking (Harrasser and Solhdju 2016) within her ecological epistemology. The justification modes for a problem and forms of research to solve it shift from justification based on objectivity and universality to justification based on the adaptation to a socio-ecological situation.

In summarizing this chapter, we will formulate a kind of working definition of the problematic by contrasting and embedding the components above. Epistemology has been constituted in modern philosophy by a separation between subject and object (Fichant 1975). Bachelard's epistemology marks an epistemological break (Fichant 1975). Epistemological break means a 'new concept of epistemology' (Fichant 1975), for which he introduces the structure of the problematic as an element of theory that builds on the mediation between the scientific subject and the object. Through this epistemological break, epistemology becomes historical. Simondon can build on this and develops his onto-epistemology, which is based on particular individual–milieu connections. Here, similar to Bachelard, the thinking structure of the problematic takes on an epistemological function for the living. Stengers, in her ecology of practices, incorporates the thinking structure of the problematic in

its epistemological function. It is a transformative tool for thinking (Harrasser and Solhdju 2016) characterized by many epistemological breaks.

With the concept of the problematic, French theory introduced a historical philosophy of science that was able to work out the dominant notions of separation: a differentiation of the subject–object dichotomy, the external and internal, world–psyche relations, or the individual and the collective. It reminds us of the historicity of how knowledge is generated and explained as knowledge. The question of how we know that we know is historically, socio-culturally, economically and politically situated. The problematic is to be understood as epistemologically relevant insofar as epistemology itself is to be understood in the following meaning: 'different ways of knowing, acting and being' (Vilsmaier, Brandner, and Engbers 2017, 170) are made up of certain cultural traditions, societal paradigms and geopolitical discourses and their historical contingencies. So the problematic is not about defining or questioning what the problem is, but how knowledge is generated (Wulz 2014, 70). Thus, epistemology has a problematic and essential function in questioning knowledge according to its respective validity. It therefore introduces the possibility of epistemologically breaking with possibly dominant normative notions of science and methods of knowledge generation, and is finally understood as an ecology of practices (Stengers 2005).

In the following section, we will interweave the thinking of the problematic with the practice of designing. In doing so, we develop the thinking practice of *problematic designing* to demonstrate its transformative power as an epistemology for transdisciplinary sustainability research.

Problematic Designing

In order to open up the historical epistemology of the problematic for transdisciplinary sustainability research, we connect it to the practice of designing and its speculative drafts in order to be able to generate sound and future-relevant knowledge. Designing is understood as a process that produces designs, which have the character of manifested ideas, always containing elements of future, uncertainty and provisionality, and can therefore be called speculative drafts. We understand future-relevant knowledge to be generated always in and with practice. Thereby, we follow a thought that has already been established by other authors who use the term 'design as a pragmatic orientation for the selection of knowledge' (Krohn, Grunwald, and Ukowitz 2017, 342, own translation) within transdisciplinary processes, and develop it further epistemologically.

Designing is considered a planning action that transforms 'existing situations into preferred ones' (Simon 1969) by using creative methods for visualization. It moves between two poles that Banz (2016) describes as 'design doing' and 'design thinking.' 'Design doing' primarily describes the making, which means the output-oriented tangible practice of design, whereas 'design thinking' includes the cognitive planning aspects of design. As a result, design is no longer solely focused on artefacts, with its aesthetic and functional demands that go hand in hand with shaping forms, but on the transformative processes of planning and problem solving, which can also be applied in political or social processes (Escobar 2018; Fry 2011; Manzini 2015; Papanek 1971).

The specific epistemic quality of designing lies in a nexus of conceptual thinking and creative making that can result in visual and tangible objects leading to new knowledge and transformative power as they change situations by their design (Peukert and Vilsmaier 2019). Designed objects have a closed nature, whereas a design process itself has a procedural and open character. This reveals the dialectic nature of design. As there is no end to a design process and no final solution, designing results in a forward-oriented openness. We will never know under which conditions a design will be consulted or assessed in the future. As Maniglier points out in his thinking of the problematic, the solution is not just given, but 'in the making' in the form of a metastable state similar to the provisional final phase of designs: 'if we problematize the world [. . .] [b]ecause our own thought proceeds as a process that structures a set of propositions. The structure is neither given in advance nor constructed: it is all in the making' (Maniglier 2012, 23). Design theories show historical parallels to the emergence of the epistemological thinking of the problematic by contributing to

a differentiation, historicity and situatedness of knowledge and knowledge production itself (Dorst 2003): the practice of designing is epistemologically situated, which means it is constituted by a specific epistemic quality, consisting of a nexus of conceptual thinking and creative making, as do designs themselves.

After referencing design and designing, and connecting it to thinking the problematic, we will introduce and explain the thinking practice of problematic designing as an epistemological tool. Therefore, we have visualized a two-dimensional representation of the epistemology of problematic designing (see Figure 1). This is influenced by Simondon´s concept of time: 'time itself is essence, not as development starting from an origin or tendency towards some end, but rather as resolute constitution of being' (Simondon in Scott 2014, 6). In his understanding time is not determined by an origin or an end, but is constituted by being (Figure 1).

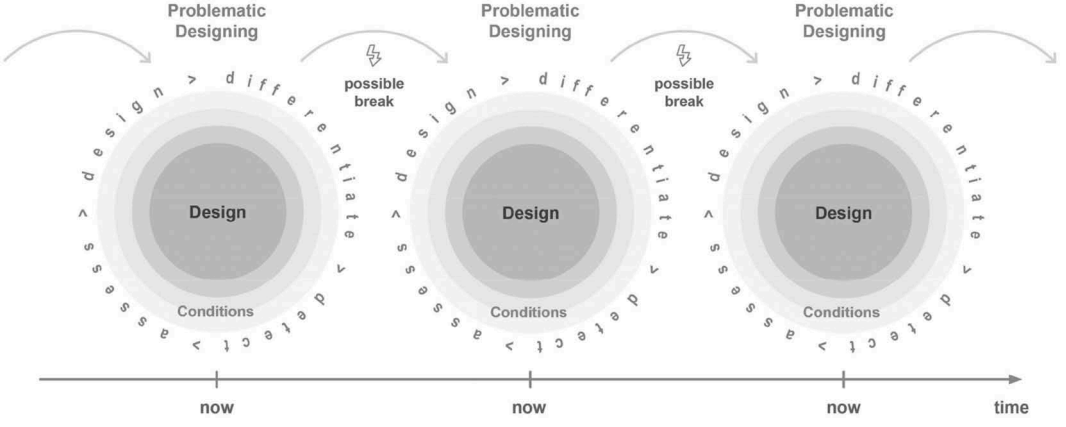

Figure 1. Epistemology of problematic designing.

The timeline in Figure 1 represents different stages of designs always in the present. These are vibrant designs embedded in milieu-like, different environmental conditions. The problematic is the differentiation between the design and the conditions that generate it, and that in turn can be generated by the design. It is a reflexive feedback movement between the initial situation, including the determining normative goal, and the result. The following steps describe problematic designing: differentiate, detect, assess (imbalance) and design. Here we recognize a proximity to the philosophical pragmatism of John Dewey, where 'reflection is provoked when action is faced with obstacles of some sort' (Barnett 2015, 21). Clive Barnett further writes, '[a]fter Dewey, problematic situations are not understood as sudden intrusions into a settled environment, but rather as something becoming off kilter in the course of ongoing activity' (Barnett 2015, 22). In the iterative movements of actively becoming, described in the quote, problematic designing focuses on problematizing and designing on an equal footing.

In the four steps (see Figure 1) lie the *transformative moment* of problematic designing. The transformative moment moves in a complementary way between forms of adaptation of the designs to existing conditions or the complete break with these conditions. 'The historicity of the sciences thus has an open future ahead of them – their objects are characterized by never being finished' (Wulz 2014, 70, own translation). Problematic designing is open-ended. It can question the respective validity of research, knowledge and knowledge production. Furthermore, the results can challenge possibly dominating, normative notions of science and methods of knowledge generation or produce an epistemological break, even if we cannot think it.[15] To regard these possible breaks as epistemologically essential and inherently in the living is a quality of problematic designing, which

makes it interesting for sustainability research. The epistemology of the problematic is extended by Simondon's terminology of *being* and *becoming*. He says in his *Psychic and Collective Individuation*, here requoted by David Scott, 'What happens occurs in the form of a putting into question of being, in other words, in the form of the element of an open problematic' (Scott 2014, 6). Being inevitably brings up questions of cognition, which is the moment of understanding and mediating with the environment.[16] Accordingly, problematic designing always happens now, as the radical now is the coordinate point of the living being. The question arises: How can one be detached from the conditions of the design while designing, to do justice to the open-ended process that also enables epistemological breaks? The constant iteration of the four steps of problematic designing allows this apparent contradiction, as in each step every aspect of the conditions can be called into question.

Discussing Implications for Transdisciplinary Sustainability Research

In this section, we refer our perspective of problematic designing to transdisciplinary sustainability research. Engbers (2018) has derived several characteristics of this form of research out of five definitions of transdisciplinarity that decisively shaped the current discourse in German-speaking countries (Jahn, Bergmann, and Keil 2012; Klein et al. 2001; Lang et al. 2012; Pohl et al. 2008; Scholz 2011). These characteristics are an orientation towards societally relevant, complex problems; a heterogeneity of involved actors with their specific knowledge; learning as part of the research process; and a strengthened relationship amongst involved actors with their specific knowledge (Engbers 2018).

As we wrote in the introduction, problem orientation, as a self-constituent feature of the discourse, can be seen as a problem-solving orientation in the publication results. We argue that the perspective of problematic designing focuses on the problem orientation of transdisciplinary sustainability research without falling into the trap of an orientation towards immediate solution identification. Problematic designing instead maintains the complex relations to society as part of its conditions, epistemically and epistemologically, as Van Breda and Swilling (2019) and Welch (2011) have also emphasized. We understand the *problematic* in the sense of a designed draft within the thinking practice of problematic designing allowing, as Isabell Schrickel writes in reference to Gilles Deleuze, 'an intrinsic differential evolution of a problematic situation' (Schrickel forthcoming). Instead of a one-dimensional, solution-oriented directionality to eliminate problems (Schrickel forthcoming) that have been identified in the past, a variety of *dimensions of transformation* are inherent in a design. They may vary between adaptation to epistemic conditions and epistemological break(see Figure 1) – which extends the horizon of a description of knowledge generation to a change in the generation of knowledge itself. By opening up manifold dimensions of transformation, the epistemological approach of problematic designing is oriented towards complexity, with its simultaneities and multiple levels, towards a change that changes change. We will thus call it a *transformative epistemology of the problematic*, and suggest that problematic designing opens new perspectives for transdisciplinary sustainability research. Transdisciplinary sustainability research is a collaborative form of research that brings different epistemologies into play – therefore it also generates manifold epistemological breaks. The fundamental consideration of this epistemological level may be the basis for a 'heterogeneity of specific actors with their specific knowledge' (Engbers 2018), and thus be essential for this kind of research (Krohn, Grunwald, and Ukowitz 2017; Mitchell, Cordell and Fam 2015). In other words, transdisciplinary sustainability research defined by its characteristics is in itself an epistemological break that represents a core theoretical element of collaborative forms of research (Tejedor and Segalas 2018; Welch 2011).[17]

Now one may wonder where the goal orientation of sustainable development is contained in the transformative epistemology of problematic designing? From our perspective, we see a possibility of the (re-)politicization, and thus (re-)futurization (Raven and Elahi 2015, 51), of sustainability-related issues. In openness, with regard to the manifold dimensions of transformation, lies the potential for political work in and through transdisciplinary research projects. By political work we mean work on interests and epistemologies that are based on experiences, and in which nothing matters except

the moment of the differentiating encounter of these differences (Maguire 2018; Vilsmaier, Brandner, and Engbers 2017). This work also relates to different interests and epistemological understandings, and thus the future of transdisciplinary (sustainability) research itself; for example, the intercultural exploration of what is understood by transdisciplinarity.

Problematic designing allows the methodological capture of the moment of the problematic difference. Regarding sustainability, this approach results in the possibility of breaking with unsustainable path dependencies that control futures. By thinking the problematic and having the possibility of an epistemological break, problematic designing allows us to leave the taken path and thus for an open 'futurity' (Raven and Elahi 2015) to arise. Unsustainable path dependencies reveal themselves in a post-positivist moment of future orientation, expressed by an accelerated escape to the front towards productivity or a Sisyphus-like problem-solving activity. Instead, problematic designing allows futurity to arise by looking at condition and design at the same time: epistemic conditions do not control the design, nor does the design control the conditions. Transferred to transdisciplinary research, knowledge can only be viewed in the tension between conditions of knowledge generation and its results.

Conclusion

Transdisciplinary sustainability research, as it is constituting itself in Europe, is characterized by a 'heterogeneity of involved actors with their specific knowledge' (Engbers 2018) as well as by the normative goal of problem solving (Nicolescu 2010). Our contribution seeks to provide an epistemological foundation for this form of collaborative research that draws a line between its two characteristics. In our epistemological elaboration, we link two terms. On the one hand, we refer to the *problematic*, which has been constituted in the twentieth-century French philosophical theories. This concept goes beyond a solution-oriented understanding of objectively given problems. On the other hand, we propose *design* as a creative and planning practice, embodying process as well as product. Design has both a reflexive, open character as well as an enclosed nature, which is based on its object characteristic. We develop the epistemological approach of *problematic designing* based on the elaboration of the characteristics of the problematic and design and by relating them to each other. The following epistemic qualities are attributed to problematic designing: it is tied back to design practices as well as their specific historical, socio-cultural, economic and political situatedness. It is an epistemological process inherent in the living, as a permanent state of being in the making, and its transformative moment lies in differentiating the design from its epistemic conditions. We describe this process in four analytical steps: differentiation, detection, assessment and design. Problematic designing forms an open structure as designing is embedded in reflexive movements and constituted by epistemological breaks in a way that design results can grow beyond their conditions.

The thinking practice of problematic designing focuses on the problem orientation of transdisciplinary sustainability research by making transdisciplinary research part of the problem, and thus of complex societal relations and their epistemological foundations (Van Breda and Swilling 2019). Through complex actor relationships in transdisciplinary sustainability research different epistemologies are brought into play. This is why this form of research generates manifold epistemological breaks, simultaneously represents such breaks, and thus extends the horizon of a description of knowledge generation to a change in the generation of knowledge itself. We call this epistemological approach a *transformative epistemology of problematic designing*.

Notes

1. Transdisciplinary sustainability research positions itself as a mode of research between academic and expertise knowledge production and between distinct scientific and societal institutions or organizations. In the course of this, it is complementary to disciplinary and interdisciplinary approaches.

2. Moritz Engbers (2018) identified the current discourse in German-speaking countries based on the following authors: Jahn, Bergmann, and Keil (2012); Klein et al. (2001); Lang et al. (2012); Pohl et al. (2008); Scholz (2011).
3. An exemplary analysis of the term 'problem(s)' has been conducted through English-language article publications in the journal *GAiA*, with the help of computer-assisted discourse studies.
4. See https://www.hkw.de/en/programm/projekte/2019/das_neue_alphabet/das_neue_alphabet_start.php.
5. To avoid misunderstandings: we do not refer to the term used by the Club of Rome, as it was prominently taken up by Manfred Max-Neef (2005).
6. For example, connecting problematic designing to John van Breda's and Mark Swilling's *emergent transdisciplinary design research (ETDR)*, understood as a methodological approach, derived from 'a case study in the informal settlement (slum) of Enkanini in Stellenbosch, South Africa' (Van Breda and Swilling 2019, 823).
7. 1884–1962.
8. 1924–1889.
9. Born in 1949.
10. For 'the concept of problematique initiates a critique of the subject–object relation in the explanation of thought in general and of science in particular. To think is not to try to tell the truth about any particular given objects (be this living organisms, things in motion or brains), as if there was a world out there waiting for us to lay our eyes on it' (Maniglier 2012).
11. Further elaborated as *singular problems* by Patrice Maniglier (2012).
12. Just as the individuation principle and the individuation process necessarily exist incessantly in life (Simondon 2007, 31).
13. Correlationism is a philosophical position claiming that 'a thought of reality that is independent from human knowledge' does not exist (Savransky 2016, 196).
14. 'Every experiment on the reality already informed by science is at the same time an experiment on scientific thought' (Bachelard 2012, 29; Fichant 1975).
15. The quality of an epistemological break, in its radical nature, makes it impossible to think of.
16. We attribute cognition to humans, but would not exclude that it is also possible for other animals.
17. The contentual qualities of the break or the transformation of science differ from those at the time of Bachelard's work. We are aware of it but do not address the differences in this paper.

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Notes on contributors

Esther Meyer is a doctoral researcher in the interfaculty research project 'Complexity or Control? Paradigms for Sustainable Development' (CCP) at Leuphana University, Lüneburg. In her research she is analyzing understandings of problems in discourses in publications on transdisciplinary and transformative sustainability sciences. She explores how certain understandings of problems are interwoven with theories about dynamics of change. Esther engages in transdisciplinary research, teaching and learning in the context of sustainability. She studied Philosophy & Economics at the University of Bayreuth and sustainability science in Lüneburg.

Daniela Peukert is a product designer and works as a design researcher at Leuphana University, Lüneburg within the project 'Leverage Points for Sustainability Transformation' and at the Methodology Center. Her research focuses on designerly knowledge production, transdisciplinarity and the role of design in transformative research processes. In her PhD thesis she explores the epistemic qualities of design processes and artefacts, and the ability of design methods to foster integration within transdisciplinary processes.

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‘Design prototyping, together with attentive moderation, facilitates collaborative processes within transdisciplinary research and thus actively contributes to co-creating socially robust and actionable knowledge as needed for future-oriented transformations, as well as its prerequisites such as trust, shared understanding and appreciation of the other.’

11.3. Article 3

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Facilitating collaborative processes in transdisciplinary research using design prototyping

Daniela Peukert*

Faculty Sustainability,
Leuphana University of Lüneburg,
Universitätsallee 1, 21335 Lüneburg, Germany
Email: daniela.peukert@leuphana.de
*Corresponding author

David P.M. Lam

Faculty Sustainability and Institute for Sustainable
Development and Learning,
Institute for Ethics and Transdisciplinary Sustainability Research,
Leuphana University of Lüneburg,
21335, Germany
Email: lam@leuphana.de

Andra I. Horcea-Milcu

Hungarian Department of Biology and Ecology,
Babes-Bolyai University,
Cluj-Napoca, 400006, Romania
Email: andraioana.horceamilcu@ubbcluj.ro

Daniel J. Lang

Faculty Sustainability and Institute for Sustainable
Development and Learning,
Institute for Ethics and Transdisciplinary Sustainability Research,
Leuphana University of Lüneburg,
21335, Germany
Email: dlang@leuphana.de

Abstract: This article explores the application of design prototyping as a creative method to support collaborative processes within transdisciplinary sustainability research and to meet the challenges they pose. By drawing on discourses on integration, mutual learning and co-production, we identified six different interrelated challenges, concerning: (1) diversity; (2) communication; (3) power; (4) epistemology; (5) personal and team; and (6) focus. We applied design prototyping in four workshops that pertained to different phases of a transdisciplinary research process and represented typical collaborative research activities. Our analysis illustrates how design prototyping contributes to addressing the challenges of collaboration, thereby expanding the methodological canon of transdisciplinary research. In particular, it helps to

create conditions for future-oriented transformations and their prerequisites, such as trust, common understanding and appreciation of the other. Consequently, we argue that design prototyping can be used to facilitate knowledge integration and collaboration among the variety of actors involved in transdisciplinary processes.

Keywords: challenges; design research; design methods; integration; knowledge co-production; transition research; transformation; co-creation.

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Biographical notes: Daniela Peukert is a Design Researcher at the Faculty of Sustainability Science, Leuphana University of Lueneburg. With a background in product design, she is interested in designerly thinking, design methods and the role of design for sustainability transformations. In her PhD thesis she explores the epistemic qualities of design prototyping and its potential to foster integration within transdisciplinary research processes and knowledge co-production.

David P.M. Lam is a Scientific and Managing Director of the project tdAcademy – Platform for Transdisciplinary Research and Studies. He is affiliated to the Institute for Ethics and Transdisciplinary Sustainability Research (IETSR) and Institute for Sustainable Development and Learning (ISDL) at Leuphana University Lüneburg. His research focuses on the amplification of impact from sustainability initiatives. He also studies the role of indigenous and local knowledge in transformative transdisciplinary processes.

Andra I. Horcea-Milcu is a Researcher at the Babeş-Bolyai University of Cluj-Napoca passionate about the role of values as leverage points for sustainability transformation. With a background in exploring social-ecological systems and experience in place-based transdisciplinary research, she is experimenting how to leverage the transformative potential of knowledge co-creation with the support of EU funding through a Marie Sklodowska-Curie individual fellowship. Through her boundary work, she aspires to contribute to managing the science|society interface, and to reframing sustainability in terms of core human values and equitable empathetic relationships.

Daniel J. Lang is a Full Professor for Trandisciplinary Sustainability Research in the Faculty Sustainability at Leuphana University of Lueneburg. He was Dean of this faculty between 2012 and 2016. Since 2016 he is the President's Special Advisor for Sustainability at Leuphana. Furthermore he is Adjunct Faculty Member in the School of Sustainability at Arizona State University and Honorary Professor in the Graduate School of Business at the Universiti Sains Malaysia. His research revolves around the further development of theoretical, methodological as well as process-related foundations of Sustainability Science. In particular his professorship focuses on cooperation and mutual learning processes between different scientific disciplines as well as science and society with the aim to develop robust solution options for sustainability problems of the 21st century.

1 Introduction

The urgency of sustainability problems, such as climate change, biodiversity loss, water scarcity and global ill-health (Clark and Dickson, 2003; Kates et al., 2001) has amplified the call for new modes of research such as transdisciplinarity (Gibbons et al., 1994; Hirsch Hadorn et al., 2008; Jahn et al., 2012; Klein et al., 2001; Newig et al., 2019). Particularly in sustainability science, transdisciplinary research approaches have been ascribed a high potential to address and contribute to solving these complex issues by including a variety of actors with diverse perspectives, forms of cognition and ways of producing knowledge (Horcea-Milcu et al., 2020; Jerneck et al., 2011; Komiyama and Takeuchi, 2006). Collaborations between researchers with different disciplinary backgrounds as well as between researchers and non-scientific actors play an essential role in transdisciplinary research (Hirsch Hadorn et al., 2008; Klein et al., 2001; Lang et al., 2012; Wiek et al., 2012).

Collaborative approaches, such as in transdisciplinary research, aim to uncover multiple perspectives, understand multifaceted situations, gain a common ground of problem definition and framing, and reveal potential complementarities across diverse knowledge systems (Eigenbrode et al., 2007; Lam et al., 2020a; Roux et al., 2017; Tengö et al., 2014). However, there is still limited understanding and agreement about how the multiple perspectives of different actors can be made more visible (Miller et al., 2014; van Kerkhoff and Lebel, 2015). To realise the full potential of transdisciplinary research, different cultures (Vilsmaier et al., 2017), power constellations (Fritz and Meinherz, 2020; Herberg and Vilsmaier, 2020), theoretical concepts, methodological and epistemic approaches, and different bodies of knowledge need to be differentiated and integrated (Jahn et al., 2012). This diversity is foundational for co-producing actionable knowledge (Mach et al., 2020; Caniglia et al., 2020) towards sustainability transformation (Messerli et al., 2019; Norström et al., 2020), yet requires an extended range of methods that foster and support collaboration. Over the past years a growing set of methods has been developed in this regard (see e.g., Bergmann et al., 2012; Defila and di Giulio, 2018). They range from scenario planning (Freeth and Drimie, 2016; Oteros-Rozas et al., 2015; von Wirth et al., 2014) and other futures methods (Pereira et al., 2018) to arts-based and performative methods (Heras and Tàbara, 2014; Juarez-Bourke, 2018; Kagan, 2015; Pearson et al., 2018). All methods face the challenge of establishing an equal footing collaboration and the inclusion of diverse ways of knowing, especially from actors outside academia. Design methods represent a potential way to address these challenges.

We conceive transdisciplinarity and collaborative processes as cutting across the fields of design research and transition research. Therefore, they can build a significant interface between both fields of research. In general design is perceived as a discipline that aims at changing the existing into desirable states (Simon, 1996) and thus can be considered a transformative practice. Within design research, artefacts and prototypes play an important role (Buur, 2018; Eriksen, 2012; Sanders, 2013; Wensveen and Matthews, 2015), representing coded knowledge (Berglund and Leifer, 2013; Lauff et al., 2020) and thus working as epistemological tools (Dickel, 2019; Ewenstein and Whyte, 2009) by supporting thought and learning processes. Furthermore, designed artefacts and prototypes can act as boundary objects[1] that link different bodies of knowledge in collaborative processes (Carlile, 2002; Heiss, 2020; Leigh Star, 2010; Salmi et al., 2012). Their visuality and tangibility complement written text and the spoken word. They enable the negotiation of different perspectives and have the potential to level hierarchies, power

and rhetorical abilities. These characteristics can be used to meet the challenges that arise within collaborative research processes. Design methods and, specifically, design prototyping, can also be used in contexts beyond design, such as political, social or transformative processes (Fry, 2011; Gaziulusoy and Ryan, 2017; Manzini, 2015). Here, we define design prototyping as a method to individually or collaboratively develop and visualise ideas, which can then be discussed and revised (Berglund and Leifer, 2013; Exner et al., 2015). To date, the potential of design prototyping for collaborative research in sustainability science and beyond has only been vaguely explored. To fill this gap, we investigate in this article how design prototyping can be used to facilitate collaborative processes in transdisciplinary sustainability research and to cope with arising challenges.

The paper is structured as follows: first, we briefly elaborate on the challenges of collaboration in transdisciplinary sustainability research. To this end, we relied on the overlapping bodies of literature revolving around knowledge integration, mutual learning and co-production, and identified six recurring challenges of collaboration within transdisciplinary sustainability research. Second, we provide a short introduction to design research and explain design prototyping in detail. Third, we present the application of the method in four workshop settings, which can be interpreted as typical activities of collaboration in transdisciplinary research processes. The description of each workshop comprises the respective context as well as the collaborative challenges the participants faced. Using these empirical examples, we showcase how design prototyping can address various challenges of collaborative research and derive design principles on how to implement and contextualise this method in different settings. We then discuss the added value and identified weaknesses of the method before we conclude with areas for further research. In the appendix, we provide guidance (e.g., a list of materials, an exemplary agenda and a guide for moderators and facilitators) for conducting a design prototyping workshop independently.

2 Challenges of collaboration in transdisciplinary sustainability research

2.1 Bodies of literature discussing collaboration

To ascertain the key challenges of collaboration in transdisciplinary sustainability research we introduce three prominent bodies of literature where these challenges are discussed, i.e., *mutual learning*, *integration* and *co-production*. These commonly argue for, and seek to deal in practice with, the collaboration of diverse groups including scientific and non-scientific actors.

Mutual learning is described as 'the basic process of exchange, generation and integration of existing or newly-developing knowledge in different parts of science and society' (Scholz, 2000, p.118). Vilsmaier et al. (2015) understand mutual learning as an 'intercultural endeavour' that 'can reveal previously neglected or ignored differences, such as ways of knowing and sense making, world views, working styles, practices, and power relations that lie beneath the surface of disciplines, professions, working fields, or sociocultural contexts' (Vilsmaier et al., 2015, p.564). Mitchell et al. (2015) highlight the context-dependency of mutual learning and that it 'occurs through social interaction (…). Learning in this sense is a process that collaboratively generates new rich insights that remain undetectable from a single disciplinary or purpose-less (in Jantsch's terms) perspective' (Mitchell et al., 2015, p.93).

The concept of *integration* is seen as the '*core methodology*' (Pohl et al., 2008, p.421) or the '*main cognitive challenge*' (Jahn et al., 2012, p.4) of a transdisciplinary research process. Defila and di Giulio (2014, p.125) describe integration as the '*very nucleus of successful inter- and transdisciplinary research*' leading to a '*common result*', which they call '*synthesis*'. Jahn et al. (2012, p.3) define integration "*as the cognitive operation that establishes a novel, hitherto non-existent connection between distinct entities of a given context*". They "*understand integration as a process that leads to a change in the structure and organisation of a problem context*" (Jahn et al., 2012, p.7). For them integration takes place on several levels – epistemic, social-organisational and communicative (ibid.) – and is complemented by the practice of differentiation.

The concept of *co-production* '*refers to processes of joint knowledge creation*' (Polk, 2015, p.111), which includes scientific and non-scientific perspectives that seem relevant to solving a specific problem (Pohl et al., 2010). Therefore, co-production includes the collaboration of different actor groups (Polk, 2015), which are jointly responsible and engage in the mutual process of knowledge generation (Tengö et al., 2014). Lang et al. (2012, p.27) devote the second of three phases in the ideal-typical transdisciplinary research process, adapted from Jahn (2008), to the co-production of "*solution-oriented and transferable knowledge through collaborative research*". Norström et al. (2020, p.2) define co-production as "*iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future*".

We have taken up the three bodies of literature above that approach collaboration in different ways. The brief overview we provide can only give a certain excerpt of the literature in the context of collaborative research and is by no means complete. The discourses overlap to some extent in their aims and cannot be sharply delineated. For us, they represent different perspectives on a common interest and therefore complement the picture of collaboration in transdisciplinary sustainability research. In our view, *mutual learning* describes the basic willingness to exchange and openness to learn from the other. This forms the basis for collaborative work. *Integration* describes the attempt to combine different bodies of knowledge and other entities within a transdisciplinary research process. Finally, *co-production* aims at collaborating to create new knowledge. The critical points of the three discourses, such as different power constellations in collaborative processes or the marginalisation of individual groups of actors, cannot be fully discussed here. However, we would like to address them through the challenges identified in the following section and show how they can be productively addressed with design prototyping.

2.2 Identifying the challenges of collaboration

For the purpose of this study we coded selected text passages holding information about various challenges from the key literature and derived six interrelated categories: diversity, epistemic, communication, power, personal and team, and focus challenge (see Table 1). We do not regard these categories as exhaustive, and recognise alternative classifications for analysing the challenges of collaborative research proposed by other authors. These also partly overlap with ours, for example in the epistemic dimension. With their integration levels (epistemic, social-organisational and communicative), Jahn et al. (2012) refer to the integration of entities as a cognitive challenge, but neglect aspects such as power and diversity. Freeth and Caniglia (2019) use a much larger grid

with their categories based on Felt's (2009) concept of epistemic living spaces, which besides the categories of epistemic and social also includes dimensions such as symbolic, spatial and temporal, which seem too coarse for our analysis. Gaziulusoy et al. (2015) make a similarly broad categorisation by distinguishing between inherent, institutional and teamwork challenges, which are also not specific enough for our case. In principle, the categories we propose are situated in a similar range to those proposed by Jahn et al. (2012), Freeth and Caniglia (2019) and Gaziulusoy et al. (2015); however, for analysing the challenges in the concrete situations of collaboration in general, and design prototyping in particular, we suggest a slightly adapted list.

Table 1 Overview of interrelated categories of challenges of collaboration in transdisciplinary sustainability research

Diversity challenge	A key challenge of this category includes "the development of an appreciative stance towards difference" (Mitchell et al., 2015, p.93). This goes hand in hand with emphasising that diversity is in itself of value (Tengö et al., 2014), an "understanding of the otherness of others" (Vilsmaier et al., 2015, p.577), as well as appreciating diversity in terms of cultural backgrounds, practices, worldviews, perspectives, methods and organisational structures (Vilsmaier et al., 2015; Defila and di Giulio, 2014; Pohl et al., 2008; Tengö et al., 2014; Lang et al., 2012)
Epistemic challenge	Here, the challenge is to achieve a comprehensive understanding that enables both the bridging of different bodies of knowledge (Jahn et al., 2012; Roux et al., 2017), with their specific methods, terms and concepts, and the finding of a common knowledge base (Vilsmaier et al., 2015). This means as well, '*recognising and explicating the limits of one's own knowledge*' (Jahn et al., 2012, p.7) and worldview. Furthermore, this implies synthesising information (Scholz, 2000), developing new methods of interaction (Tengö et al., 2014), avoiding simplistic solutions (Roux et al., 2017) and mastering ambiguity (Defila and di Giulio, 2014; Lang et al., 2012) and multiple framings (Polk, 2015)
Communication challenge	The aim of successful communication is mutual understanding (Jahn et al., 2012). Challenges that have to be overcome consist of dealing confidently with misunderstandings (Roux et al., 2017), translating the phrases, communication styles and definitions of various disciplines and stakeholder groups into accessible forms (Jahn et al., 2012; Pohl et al., 2008; Polk, 2015; Vilsmaier et al., 2015), exchanging the meaning of terms (Pohl et al., 2008), recognising the contextualisation of everyday language (Pohl et al., 2008) and enabling an intercultural dialogue (Tengö et al., 2014; Vilsmaier et al., 2015)
Power challenge	The power challenges concern the transparent handling of hierarchies due to status, educational background, social positions or cultural hegemonies (Pohl et al., 2010; Vilsmaier et al., 2015), the handling of an alleged superiority of a specific form of knowledge (Roux et al., 2017), the balancing of '*contributions between very active and very passive participants*' (Vilsmaier et al., 2015, p.575), groups and stakeholders, the '*balancing [of] societal relevance with scientific rigor*' (Lang et al., 2012, p.32) and the inclusion of local knowledge (Tengö et al., 2014)

Table 1 Overview of interrelated categories of challenges of collaboration in transdisciplinary sustainability research (continued)

Personal and team challenge	The challenges of the personal and team category include dealing with interpersonal tensions, disagreements and fears (Lang et al., 2012; Roux et al., 2017), finding skilled members and selecting the actors involved (Pohl et al., 2008; Roux et al., 2017), dealing with discontinuity of participation (Lang et al., 2012) and agreeing on fundamental values (Tengö et al., 2014)
Focus challenge	The focus challenge can be considered to be in tension with the diversity challenge, because after the openness characterising incipient stages of collaboration, a certain narrowing down is necessary to enable targeted project results. The challenges of this category therefore include the development of the same problem understanding and the formulation of a common goal (Jahn et al., 2012; Lang et al., 2012; Polk, 2015; Tengö et al., 2014)

3 Design prototyping as a collaborative method

The understanding of design research underlying this paper is based on the concept of 'research through design' (Findeli, 1998; Frayling, 1993; Jonas, 2012), i.e., research that applies or uses design methods and processes, such as drawing or prototyping. In doing so, the design researcher is directly involved in the research process and takes an active and formative role. In order to understand how design practices are applied in contexts beyond design, we refer to an extended understanding of design. In such, design and its methods no longer focus solely on designing artefacts for their aesthetic and functional demands, but can be seen as practices with transformative potential. If design is detached from the artefact and the design context, it can also be used as a planning and problem-solving practice in other fields. This may involve political and social processes (Escobar, 2018; Fry, 2011; Manzini, 2015; Papanek, 1985) or transformative sustainability research. Thereby, design particularly benefits from its interdisciplinary quality and the visual power of creative methods to make ideas understandable for others. The nexus of conceptual thinking and creative making reveals the true meaning of design, which can result in visual and tangible objects that lead to new knowledge and hold transformative power as they change situations through their design (Meyer and Peukert, 2020; Peukert and Vilsmaier, 2019).

In this paper we focus on a design method called design prototyping. In general, this is a method to individually or collaboratively develop and visualise ideas, which can then be discussed and revised (Sanders, 2013; Sanders and Stappers, 2014; Stappers, 2013). The term prototyping describes the process of constructing small two- and three-dimensional designs, which can vary in their level of quality (Exner et al., 2015; Hallgrimsson, 2012; Moeller, 2008) from so-called mock-ups (low quality) to functional or technical prototypes (high quality). Mock-ups are small models made with inexpensive materials and are used to validate a design by taking the first step from sketch to three-dimensional, tangible form. They are a communication and discussion medium and can be adapted and developed through discussions between users and designers or in the design team. Various low-priced materials such as paper, cardboard, plastic or household items (e.g., sponges, foils or wooden skewers) are used. Out of these, the designing person – alone or together with other team members – builds an idea or a specific aspect

of an idea in a short time. Design prototyping, as it is understood in this paper, is similar to mock-ups regarding its quality, can be done by anyone and does not require specific technical knowledge or skills. All materials and prototyping techniques are allowed. The artefacts created do not have to satisfy any aesthetic or functional requirements, but rather serve to reflect, verify, visualise or communicate and discuss an idea or thought. In this respect, applying design prototyping in transdisciplinary research processes also differs in some ways from its application in design disciplines (Peukert and Vilsmaier, 2021). These include the role of the designer as facilitator, the context detached from design, and the stronger focus on exchange and collaboration rather than product outcomes or verification of aesthetic-formal features, technical functionality or user acceptance. The reflecting, testing and exploring qualities of design prototyping are similar to what is called tinkering in design practice. Nevertheless, we have deliberately chosen the term prototyping to link to discourses around the professional practice of material objectification of futures (see Dickel, 2019). In our examples, it is the future of regions that is not directly manifested in products or services in the workshops, but through the work of the actors who live and work in these regions.

The tangibility of the resulting design prototypes is one of the main reasons why this method was chosen from a variety of different design methods, as we expect it to enrich the possibilities of expression and discussion within transdisciplinary groups. Furthermore, prototyping processes can be performed both individually and collaboratively in a group. When prototyping individually, each participant is asked to build an item relating to one specific aspect of the objective of the workshop. Thereby, the method helps people to reflect on their own position and gives them time to visualise these. When prototyping collaboratively, the participants are asked to work together in building a specific aspect. Here, prototyping has the character of a discussion, but through the help of the objects, ideas and arguments can be made visible, jointly developed, moved and built upon each other. Furthermore, the elements can be deconstructed and rearranged. The designed prototypes have the character of manifested ideas, holding speculative elements of future, uncertainty and provisionality. Therefore, design prototyping seemed particularly suitable for collaborative work in transdisciplinary research and the challenges that arise in such processes.

4 Design prototyping in practice: experiences with four inter- and transdisciplinary workshops

We describe the method of individual and collaborative design prototyping and its collaborative potential using four workshop examples (see Table 2). All four instances of design prototyping were applied within the research project "Leverage Points for Sustainability Transformation" (LP). The project included two place-based transdisciplinary case studies: one in Lower Saxony, Germany and one in Southern Transylvania, Romania. The aim of the Lower Saxony case study was to form alliances within a biodiversity corridor to make the Oldenburg area fit for the future. In comparison, the aim of the Southern Transylvania case study was to enable sustainability-transformation processes in Southern Transylvania, with a special focus on amplifying strategies to increase the reach of local sustainability initiatives. The transdisciplinary collaboration in both case studies included numerous working meetings, field trips of individual researchers and 23 workshops (10 in Lower Saxony and 13 in

Southern Transylvania) with local actors. Additionally, there were other joint activities such as conference visits, and local events were held on topics including climate, local food or art. A variety of different methods (e.g., qualitative, quantitative and arts-based) were used in the workshops, each appropriate to the project phase, its goals and the participating actors. The four selected workshops showcase the application of design prototyping in the most diverse collaborative situations within a transdisciplinary research process, and exemplify its specific function in the series of workshops in each case study (Table 2).

Table 2 Overview of prototyping examples within transdisciplinary workshops

Workshops	*LP Team Workshop, Lüneburg* (A)	*LP Case Study Transylvania, Romania, NGO Workshop* (B)	*LP Case Study Transylvania, Romania, NGO Workshop* (C)	*Transformations Conference, UK, Practice Session/ Workshop* (D)
Collaborative research activity	Interdisciplinary team building	Transdisciplinary visioning	Visioning with a specific local actor group	Interdisciplinary sharing, disseminating and discussing of preliminary research results
Guiding question	How to bring together local needs, own and group research? How to get to know each other and their research interests?	How to bring together the work from different initiatives and make them visible?	How to work together and develop the association in the future?	How to share research results and research experience and combine them with a new conceptual approach?
What was built during design prototyping?	In four individual steps: the case study area, the research project, the personal research and potential connections	In step one individually: contribution of organisation to the shared vision; in step two collaboratively: common pathway to the shared vision	In one individual step: wishes for the future of the association	In two individual steps: a sustainability initiative's relation to one of four amplifying mechanisms; the increased impact of this initiative
Goals of workshop	Reflecting connections to case study area, work package and own work. Discover the connecting potential	Visioning about future of Southern Transylvania, reflecting own contributions, discussing joint contributions, formulating of a guiding question for the further project	Reflecting and communicating wishes for the association in the future (individual reflection, group discussion)	Reflecting sustainability initiatives, their increasing impact and relation to amplifying mechanisms

Table 2 Overview of prototyping examples within transdisciplinary workshops (continued)

Workshops	*LP Team Workshop, Lüneburg* (A)	*LP Case Study Transylvania, Romania, NGO Workshop* (B)	*LP Case Study Transylvania, Romania, NGO Workshop* (C)	*Transformations Conference, UK, Practice Session/ Workshop* (D)
Challenges addressed				
Diversity	x			x
Epistemic	x			x
Communication	x	x		x
Power		x	x	
Personal and team	x	x	x	
Focus	x	x	x	
Participants	Researchers with different disciplinary backgrounds (e.g., law, ecology, sustainability science, geography, economy)	Local actors (scientific and non-scientific) working in NGOs on nature conservation, cultural heritage conservation, supporting small-scale, traditional or organic farming, agro-tourism and ecotourism, and rural community development	Local women from Viscri/Romania working for the association 'Viscri incepe'	Researchers with different disciplinary backgrounds interested in topic, method and case study
No. of participants	11	28	12	9
Practices of the involved participants	Producing research	Working for the purposes of the NGOs	Producing knitted and felted products for income, but also for the purpose of the association	Sharing and discussing research ideas and outcomes
Collected data	Pictures, audio, questionnaire, researchers' reflections	Pictures, audio, video, questionnaire, researchers' reflections	Pictures, audio, video, interviews, researchers' reflections	Pictures, audio, questionnaire, researchers' reflections

Workshop A describes the use of design prototyping within an interdisciplinary team-building workshop of the LP team in the first year of the project. In Workshop B design prototyping was applied to support a transdisciplinary visioning process amongst the non-governmental organisations (NGOs) of the case study area in Transylvania in the problem-framing phase of the project. Workshop C also illustrates a visioning process,

but with very specific actors in one Transylvanian village. Workshop D shows the application of design prototyping within a conference workshop to disseminate and discuss the first research results of the Transylvania case study amongst scientists. The selected workshop examples in this article each represent a typical activity of collaborative research carried out in transdisciplinary processes. They represent single events of the transdisciplinary research process of the project, but are not all necessarily transdisciplinary in themselves.

The structure of the design prototyping method was similar in all four workshops. The participants took their seats at large worktables (6–10 people). In one workshop the participants were randomly assigned to the tables in order to achieve the greatest possible mixing, while in others they sat down at the tables as they wanted. The tables were lined with large sheets of paper to create a working atmosphere. The working materials (paper, cardboard, pencils, wooden building bricks, etc.) for the design prototyping were placed in the middle of the table and the participants could take them without any restrictions (see Figure 1). In front of each participant was a cardboard plate that served as a platform for the individual prototyping. This enabled the prototypes to be lifted, shown or transported later. When there was a step of collaborative prototyping, a common platform was created in the middle of the table. The time devoted to each prototyping part was limited to 20–30 min. During the workshops, design prototyping was embedded in several other workshop steps, such as a presentation and introduction, a warm-up, a reporting back to the group or plenum, a plenum discussion, and a feedback and closing step (see also the exemplary agenda in the Appendix). Design prototyping was used to individually and collaboratively reflect, visualise, explain and discuss specific aspects relevant for the guiding question of each workshop (see also Table 2). A design researcher (first author of this paper), who was supported by assistant researchers at the tables depending on the size of the group, moderated the workshops. Other researchers observed and documented the process. The workshops were documented by pictures, audio recordings, questionnaires and post-event reflections of the researchers.

Figure 1 Setup of workshop tables with design prototyping material and cardboard plates (see online version for colours)

4.1 Interdisciplinary team building (Workshop A)

This workshop took place in the first year of the project (August 2016), when it was still in a scoping phase regarding case studies. Within this phase we used design prototyping as an interdisciplinary team-building technique for the Leverage Points team. In four steps 11 researchers from the team with different disciplinary backgrounds (e.g., law, ecology, sustainability science, geography, economy) came together to reflect on the connections between the case study area, their work package (ReStructure, ReThink, ReConnect) and their own research questions. First, we asked them to think of the case study area and to individually prototype its merits and needs. The second question included thinking about the LP project in general and their work package (ReStructure, ReConnect, ReThink) in particular, and individually prototyping the main research aims. Third we asked them to reflect on their own research interests and to prototype them. The final step was to look at the different elements they built and search for connections, combinations or bridges. After finishing this each researcher presented their prototype to the other team members, which was followed by a group discussion and individual reflections on the prototyping process. The overarching aim of this workshop was to find out about how to connect local needs, own and group research, and to get to know each other personally and through respective research interests.

There were several kinds of collaborative challenges facing this group. The researchers came from different countries with different cultural backgrounds. Furthermore, they were from different scientific disciplines and some of them had years of practical experience outside the scientific community (diversity challenge). While some researchers worked very much with quantitative methods, others worked exclusively qualitatively (epistemic challenge). In addition, great openness was required of all participants to think their way into the specialist areas of their colleagues and to exchange specific terms and concepts (communication challenge). Another challenge for the team was to deal with the fact that a very important position had to be filled early on in the project: it had been vacant for a long time, which resulted in some responsibilities not being clearly divided, or disagreements about them (personal and team challenge). This also meant there was some uncertainty about how to reconcile the different interests related to the research of individuals, the team, the project and the case studies (focus challenge).

4.2 Transdisciplinary visioning (Workshop B)

The second workshop took place in Sighisoara, Romania in September 2016, involving 30 regional stakeholders of existing NGOs in the area of Southern Transylvania. The aim of the transdisciplinary case study was to facilitate and support sustainable transformation processes in the region. The basis was a future scenario for the region in the year 2043, which was collaboratively developed with actors from the region and researchers in a previous project (Hanspach et al., 2014). The aim of the workshop was to identify the NGO contributions to the vision of the future, to develop initial ideas for cooperation between the various NGOs and to support further trust building (Lam et al., 2020b). For these tasks design prototyping was used in two steps. In an individual prototyping step, the participants were asked – as representatives of their initiatives – to reflect on the existing contributions to the sustainable future vision and to build them with the given material. The resulting prototypes were then presented to the other participants in a small

group (6–8 people in each group). In a second step, the participants were asked to discuss a common approach based on their individual contributions and to build this approach together with the given material and the existing prototypes. The common prototypes of each group were then presented to the other groups. Based on the design prototyping experiences, a plenary discussion was moderated to identify the drivers and barriers that promote or hinder the achievement of the vision. The group also discussed the further needs of the organisations to reach the common approach they built in the design prototyping process, as well as missing actors, knowledge or structures.

The challenges of this workshop arose from the fact that the participants worked for different NGOs that have various aims (e.g., nature conservation; supporting small-scale, traditional or organic farming; agro-tourism and ecotourism) and interests in the region. Talking about the different interests, promoting mutual understanding (communication challenge) and defining a common goal was a big task (focus challenge). Furthermore, the NGOs are differently equipped and networked, so it was also a matter of balancing out power differences (power challenge) and also to some extent overcoming old tensions and misunderstandings (personal and team challenge).

4.3 Visioning with a specific local actor group (Workshop C)

In the third workshop example design prototyping was used within a phase of working together with local actors. It took place in January 2018 in Viscri, Romania. The actors were women from the association 'Viscri Incepe' (translation: 'Viscri Begins') in the small village of Viscri, who are knitting and felting products to support their families' income and strengthen community services. The association involves around 80 women, who coordinate the production of the handicraft products and distribute them. The products are sold to visiting tourists in a little shop in Viscri, online via a webshop and at Christmas markets, for example in Germany. The approach is fruitful: women generate additional, season-independent earnings through their work. This is especially important in winter, when no income can be achieved through agricultural work. But it is about much more than that – the women have recognised that their craft is significant and that they can thus change something in their community. In addition to the economic success, the association has also contributed to further changes in the village: for example, it established an afternoon homework help program for children, supports the travel costs for students who attend secondary school in the city, operates vocational orientation seminars and language and computer courses for young people, and enables access to health services like medical screenings, especially for women and elderly people. As part of the transdisciplinary case study, we were trying to find out about the women's future wishes for their association and their needs. In this case we chose the design prototyping method because the women are very skilled in using their hands but have little experience of speaking up in workshop settings. Using different materials to prototype their wishes, they were able to express their thoughts in a different way and came up with new ideas, building on each other's inputs. For example, they had the idea of integrating younger women into the marketing and online sales of the association's products to teach them skills they can also use on the job market. The insights gained in the workshop mainly influenced the further ongoing process with multiple stakeholders involved in the selling of the products, the planning of further trainings and the amplification of the association's work.

The challenges of this workshop were as follows: participants had different positions within the association – some were in leading positions and had good relationships with the partners with whom the association is connected, while others were simply members who knit regularly for the association. This difference in power had to be balanced out (power challenge). There were also tensions considering the quality of the goods, the payment, the assortment, the distribution of tasks and the contacts with the partner organisations (personal and team challenge). These tensions had to be bridged while working on a common vision for the association (focus challenge).

4.4 Interdisciplinary sharing, disseminating and discussing of research results (Workshop D)

The fourth workshop example was called 'Creating pathways for transformation through amplifying approaches: a case-study from Southern Transylvania' and took place during the Transformations conference in Dundee, Scotland in September 2017. In this three-part workshop we used design prototyping to disseminate the first results of our project and case study work. First, we introduced the participants to the [Project Name] project context, the case study in Transylvania and our research on amplifying processes that increase the impact of regional initiatives. Second, we asked the participants to prototype a sustainability initiative they have experience with in relation to one of the four amplifying processes presented, and explain how this initiative has increased its impact. The participants then presented their prototypes to their group at the table. As a third step we had a discussion in the plenum about the challenges the initiatives encountered when increasing their impact, how to overcome these challenges and the role that amplifying mechanisms could play in overcoming them.

The challenges of this collaborative workshop at a conference occurred because the participants came from various scientific disciplines, countries and institutes (diversity challenge) and had different interests in our workshop (some were interested in local work in Romania, others in the Leverage Points concept and still others in working with amplifying mechanisms). The aim was to bridge these different interests, to convey our findings to the participants and at the same time to include their experiences and let them share the latter with each other (epistemic and communication challenge).

5 Potential and limitations of design prototyping

5.1 Contributions of design prototyping to addressing the challenges of collaborative processes in transdisciplinary research

To better understand how design prototyping contributed to addressing the named challenges we employ collected data from each of the four (A–D) workshops: i.e., images, audio and video recordings of the workshops, and, especially, the questionnaires, ex-ante interviews with participants and observers, and the observations and reflections of the researchers. We transcribed the audio recordings, interviews and research reflections and qualitatively analysed them with regard to the challenge categories, then checked our initial findings by reviewing the image and video material.

5.1.1 Diversity challenge

Observations of the prototyping process show that each participant has a different perspective on the built object (prototype) in the middle of the table (see Figure 1), simply because of its spatial situatedness. It seems that different perspectives on a subject matter are easier to negotiate in view of the object than if it is only spoken about. Furthermore, it is obvious that each participant builds something different. These differences can be easily recognised on the concretely built object and appreciation of the other can be expressed. Sometimes diversity seems to be easier to recognise in objects than in people themselves, with their different backgrounds. It can be observed that the playful element of design prototyping bridges some hesitations regarding these differences, encouraging a plurality of expressions: "*The material allowed me to think creatively about a system that doesn't usually inspire creativity*" (Participant WS A).

5.1.2 Epistemic challenge

The colour, feel and texture of the materials appeal to different senses and thus also stimulate the thinking process. "*Very good material indeed. It helped structuring my ideas and fantasy*" (Participant WS A). The material invites the participants to translate or transfer complex facts, terms, thoughts and concepts into visual and tangible objects, thus simplifying, translating and synthesising them. "*But first it kind of helps you to quiet down all the noise in your head and to build something when you're in the moment only with the object.* (...) *It helps with managing complexity*" (Participant WS A). "*By providing a limited set of materials, it promoted creative thinking*" (Participant WS B). Accordingly, attitudes and ideas are also transferred into objects, which in turn are sometimes easier to transform than the thoughts themselves. The participants negotiate their own and others' thoughts on the prototypes in a reflexive individual and collaborative building process. It seems easy to recognise and explain relations via the concrete object and to further develop them together. As a result, underlying knowledge can be discussed and made clear, but also presented in terms of language and text. Working on objects enables bridging of participants' different bodies of knowledge. Design prototypes appear as visual and tactile object-related metaphors, which can be interpreted in many ways. Text and language are supposed to be unambiguous – this is not the case with visuals and objects. By working with visuals and objects ambiguity and multiple framings seem to be better accepted.

5.1.3 Communication challenge

In using design prototyping, language (oral and written) is supplemented by the visual and tactile dimension, making communication more diverse; language barriers can be negotiated and bridged in the object. Phrases, definitions, concepts etc. are translated into visual and tactile objects and thus become accessible in a different way. While speech and text usually only address the two senses of sight and hearing, design prototyping also addresses touch and, in part, smell. '*I chose material that feels nice to touch*' (Participant WS A). The design prototypes serve as a communication medium within the dialogue of the participants. The process enables a spatial location of the objects, which can then also be viewed and discussed from different perspectives. As visual and tactile metaphors, design prototypes help to overcome language barriers. By structuring the workshops into individual and collaborative phases of prototyping, explaining, listening and discussing,

every participant is encouraged to get involved. We were observing that in this way, participants who normally do not speak out in groups – for example because they are shy, do not have high status or are not so well versed in rhetoric – have an equal say, which should promote mutual understanding. "*Initially everybody was busy creating their own 'table' but when we started to explain the communication exploded*" (Participant WS B). Participants were invited to ask questions to prevent misunderstandings. Questions about the object like, What does this part here mean? What does the colour stand for? What does this material represent? etc. are easier questions to ask than those related to a certain concept. "*It was a way to come up with another level of discussion and another entry into the discussion. This created an atmosphere where a discussion was possible that went beyond the individual needs*" (Observer WS C). Simply asking another participant at the table to pass a certain material or a pair of scissors can build a communicative bridge and soften previously hardened fronts.

5.1.4 Power challenge

Since prototyping is almost always foreign to all participants, we observed that it brought them to the same skill level. Differences in status, educational background or social positions are levelled out. "*The workshop was a good step for them in general, it helped them to speak out. It empowers them. They have creative potential but don't know it yet*" (Observer WS C). Due to the structure of the prototyping workshops, with individual and collaborative steps, differences between very active or passive participants are also balanced out. Within the prototypes every contribution or type of knowledge is equal. We were observing that explanations and discussions via the objects led to a certain degree of indirect communication: participants do not look directly into each other's eyes but hint at the object. In this way linguistic and power-related differences seem to be adjusted.

5.1.5 Personal and team challenge

Design prototyping promotes both personal reflection and collaborative work. Ideas can be jointly developed and discussed using the prototype, and various prototypes facilitate decision-making in the team. Furthermore, the development of an idea, criticism of the object, or deconstruction and reassembling of a prototype with other parts leads to this being done on the object instead of being taken as personal criticism by the person who had the idea and built the prototype. Through joint prototyping, the participants regain an innocuous way of working and communicating with each other, thus overcoming old tensions.

> "I guess one thing which is really fascinating about this method is, to use it here it's already quite non-confronting, but if you have a group of people who are potentially quite confrontational, this is really a kind of non-violent way for people to express themselves at the beginning. I think it makes a huge difference to how the conversation starts, because you're playing. So people are in a kind of playful mind, when they start discussing things. Rather than "You're the person I disagree with." I think in that complex really this is a fascinating kind of approach getting people to communicate with each other" (Participant WS 4)

Furthermore, it helps to express one's own or the institution's needs and fears without being too much at the personal level. "*The most important need is the confidence in themselves*" (Observer WS 3).

5.1.6 Focus challenge

During the workshops we were observing that collaborative prototyping helped the participants develop a common understanding of the problem and goal. This was done by reflecting on their own positions, explaining them to each other, discussing various aspects, finding and moving elements around, assigning meaning to objects and finding connections during the joint building process. In this way, participants' own positions were negotiated in relation to those of others until a common attitude was developed, which then served as a starting point for further decisions. Since the prototype is physically present, it is possible to refer back to it during the research process.

The use of design prototyping in different situations of transdisciplinary processes performing typical collaborative research activities extends the methodological repertoire of transdisciplinary research by transferring a method from design practice to sustainability science. The results of the workshops show that design prototyping seems to be effective in all interrelated challenging areas of collaborative research. In this regard design prototyping has at least four specific qualities complementing other methods used (see Table 3).

Table 3 Overview of qualities of design prototyping

Process-object quality	Design prototypes have an inherent process character, as well as an object status (Ewenstein and Whyte, 2009). This means they are at the same time becoming and completed (Peukert and Vilsmaier, 2019). For the collaborative research process, this means that on the one hand they represent results, but on the other hand they can be worked on at any time. They also make it possible to refer back to them at a later date
Visual-tactile quality	As a material form of expression design prototyping complements language and text and reduces their dominance in communication. This makes the method particularly relevant for the co-production of knowledge when participants are involved in the process who are rhetorically not so well versed, for example, or simply prefer other means of expression than language, or generally when different languages are spoken
Spatial quality	The spatial location of design prototypes enables the negotiation of different perspectives on them
Metaphorical quality	The visual metaphoric of design prototypes allows access to thoughts beyond language. For example, some participants in the workshops used green or natural materials to symbolise nature

5.2 Identified limitations of design prototyping and potential coping strategies

Although the method proved to be very helpful in the workshops and was evaluated positively by the participants, some weaknesses also became apparent. These concern the craft-playful character of the method, the group situation, the limitations of the material and the contextuality of the method. For example, some participants found the workshop situation and presenting their own ideas new and uncomfortable. At the beginning of Workshop C, the members of the handicraft association were very reluctant to bring in their own ideas and present them to others, as it was very unusual for them to work in this kind of way. This was in contrast to our expectation that the skilled women would find prototyping easy. In the interviews we were pointed to the fact that this could be partly

due to the socialist school education in Romania, which was very collective orientated and did not value individual and creative contributions. It was not very common to do something on your own and to be asked for your opinion and not be told what to do. It took the women a while to feel comfortable with the method, but then they enjoyed it and also came up with new ideas, building upon each other's input. "*Once someone starts modelling in 2D, the others follow. The designs they make are rarely 3D. Some also copy others. They joke about the exercise, they find it playful, but seem to enjoy it*" (Observer WS C). The playful element of the method could mean that the process is not taken seriously, but this can be countered by effective moderation and responding to emerging uncertainties and questions at the beginning of the process.

Another weakness is that a few participants felt restricted in their expression due to the limited prototyping material. They reported that they find it much easier to express themselves through language, which also allows them to be more precise. On this point it should be noted that limiting the means of expression can be an advantage when it comes to simplifying one's own language and thus making it understandable for others; this is a difficult step to take, however. Moreover, it is the openness in the interpretation of the objects that makes it possible to connect with the thoughts of others. A further limitation reported by some participants resulted from their own aesthetic demands. "*To be honest, I felt a bit limited by this method because of my own expectations to do something nice*" (Participant WS A). Again, it is the task of the moderators to make clear that it is not about building something beautiful, but about reflecting on and communicating one's own thoughts. A weakness related to the challenges of power and team is that individual participants may dominate the common prototyping process. Again, the facilitators were charged with balancing the process and encouraging all participants to get involved (see also the moderation guide in Appendix).

Finally, a limitation concerning the epistemic dimension of design prototyping is that the resulting artefacts are not self-explanatory. This means that their interpretation cannot be independent of what is said about them. This is not a problem for the workshop process. For a detailed empirical analysis of the material, however, the objects must always be evaluated in conjunction with the audio recordings. Furthermore, the ambiguity of the objects can overwhelm some participants, but this is also where the opportunity to connect with the thoughts and ideas of others lies. It should also be noted that although design prototyping can be used to meet various challenges of collaborative research, the method is not a self-runner in itself, but requires sensitive facilitation and precise adaptation to the project, group, process and context. Questions or reservations should be clarified at the beginning and the moderators should provide assistance when tensions and uncertainties arise (see Appendix for moderation guide). This places high demands on the moderation skills of the persons carrying out the design prototyping process.

5.3 Future research

The application of the design prototyping method in the four workshops served primarily to find out what influence the method has with regard to tackling the challenges of collaborative research and to identify strengths and weaknesses. This paper served as a basic description of the method and its application in the four different examples of collaboration within a transdisciplinary research process and as an exploration of how the

method can contribute to overcoming collaboration challenges in these processes. We see further research needs for the use of design prototyping and its collaborative potential, especially in the detailed analysis of empirical data, for example through qualitative content and artefact analysis. Thereby the process and functions of the prototypes could be illuminated in more detail, the role of prototypes as boundary objects could be investigated, or the effect of design prototyping on enacting change at different levels could be evaluated, for example on a personal level (competencies), on a community of practice level (trust as a prerequisite for transformation processes) and on a societal level (contribute to fostering transformation). In order to address particular challenges, the workshop settings could be specifically designed to overcome them. Another possibility would be to examine the process of design prototyping via video analysis to elucidate exactly how the participants interact with each other and the prototypes.

6 Conclusion

The results of the workshops and the feedback of the participants show that design prototyping is a concrete and useful method to facilitate collaborative research activities in different phases of a transdisciplinary process and to meet the challenges that come along with it. Participants and observers particularly emphasised the improved communication, the creative approach to individuals' own ideas and attitudes, and the non-confrontational potential of the method. Taking into account its limitations, such as the selection of the material, the craft-playful character or contextuality of the method, design prototyping can be used in a targeted manner to improve collaborative processes in transdisciplinary research and other collaborative contexts. It therefore has the potential to extend the methodological repertoire in such processes.

The methodological use of design prototyping has an explicitly mediating and integrating character (Peukert and Vilsmaier, 2019), since all actors have equal rights in the individual and collaborative design process. Internal and external perspectives are conveyed and made visual and tangible with the prototypes, which can then be discussed and revised. The visuality and tangibility of design prototypes complement written text and the spoken word. By throwing participants back to the little-used and established expression of three-dimensional representation, actors with different professional backgrounds and hierarchical levels move to a similar level of ability. Existing differences, e.g., in terms of power or rhetorical abilities, which emerge in heterogeneous teams, are compensated for. The designed prototypes represent coded knowledge and serve to exchange, communicate and discuss an individual's own thoughts to others, which means they support thought and learning processes. Their process-object, visual-tactile, spatial and metaphorical qualities address the challenges of collaboration at different levels. Communicative and epistemic differences are bridged, power gaps are balanced, tensions in the team are overcome and a common focus is created – while recognising the value of different perspectives. Consequently, design prototyping, together with attentive moderation, facilitates collaborative processes within transdisciplinary research and thus actively contributes to co-creating socially robust and actionable knowledge as needed for future-oriented transformations, as well as its prerequisites such as trust, shared understanding and appreciation of the other.

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Appendix: practical guide for the application of design prototyping

General preparation

- Define the topic and aim of the workshop.
- Define questions that should be answered by design prototyping individually (task 1) and collaboratively (task 2).
- Think of questions for the discussion.
- Documentation: How should the workshop be documented (pictures, audio recording, video recording, observation notes, etc.)? The documentation also depends on what is done with the results and how the data are evaluated.
- Design a reflection sheet. Potential questions could be:
    - How did the material help to reflect a specific standpoint, conflict, etc.? (Describe your individual experience.)
    - How did the design prototyping help the collaborative process? (Describe the group experience.)
    - In general: Which materials did you choose? Why?
    - What did you build? Which elements stands for what?
    - How did the material influence, inspire or support your thought process?

- Who should be invited as participants? Invite them.
- Who should be the facilitators? Invite them for a pre-meeting.
- Buy/organise the material.
- Prepare the room and tables.

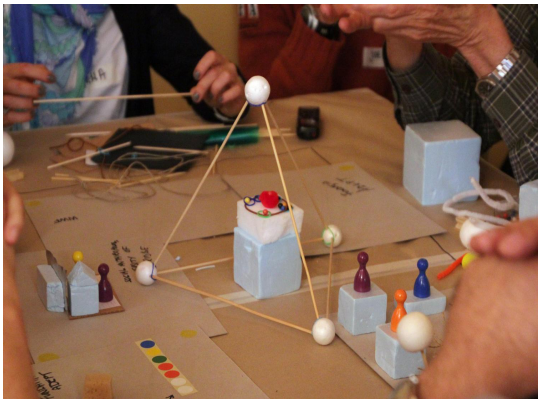
Exemplary agenda for a design prototyping workshop of 3 hours' duration

Duration	*Steps*	*Format*	*Description of the steps and guide for the main moderator*
5 min (15 min)	Introduction	Plenum (sitting)	• *Welcome*: Introduction of the hosts/moderators/facilitators • Optional introduction of participants: Name, background, organisation, interest • Agenda and general information: Why are we here? What is next? etc. Prototyping as a hands-on method of reflection and co-creation. Explain aim and advantages of this designerly method and role of visuality and tangibility • Seating: Split the participants into diverse groups. Ideal are tables with max. 6 persons/table (e.g., from different disciplines, organisations) and one facilitator per table • Ask the participants to *not interrupt* the process by using digital devices • Ask for *permission* for the documentation: pictures, audio, video, reflections sheets, observations • Ask for *questions*
15 min	Warm-up	Plenum (standing)	Start with a warm-up exercise, e.g., an *object-related warm-up* (see explanation for further details).
30 min	Individual prototyping	At each table (sitting)	Each participant builds his or her prototype in the *individual prototyping step* (see explanation for details) answering Task 1.
15 min	Individual presentation	At each table (sitting)	Each participant *explains* his or her individual prototype to the other members of the group.
30 min	Collaborative prototyping	At each table (sitting)	Each group works together in the *collaborative prototyping step* (see explanation for further details) answering Task 2.
15 min	Written reflection	At each table (sitting)	Each participant is given a *reflection sheet* and asked about their experience with the prototyping process.
10 min	Short break		

20 min	Group presentation	Plenum, but sitting at the tables or standing around them	One member of each group *explains* their collaboratively produced prototype to the other participants of the workshop.
25 min	Plenum discussion	Plenum, but sitting at the tables	The *plenum discusses* the prepared questions.
15 min	Close	Plenum, but sitting at the tables	• *Thank you!* • Ask for *feedback* on workshop, process, etc. • *Check-out*: e.g., take-home idea • Clean-up

Figure A1 With the help of individual prototypes participants discuss their ideas (see online version for colours)

Figure A2 Example of a co-designed prototype representing joint efforts towards a vision (see online version for colours)



Explanation of individual steps of the prototyping process

Object-related warm-up

Description: One desk is prepared with a selection of different materials from the list. The participants are standing around the table and are asked to think of the topic of the workshop and choose an object from the table, which should represent a specific aspect of the topic of the workshop. Each participant is asked to explain their choice to the others and to put the object on a separate table. This is followed by a short discussion about the link between the materials (all chosen objects on the table).

Aim: The object-related warm-up helps the participants to get to know each other, makes them reflect and visually describe their idea of the topic of the workshop, and puts them into a creative mode. This part of the workshop stimulates participants to express their visions. Main functions of object-related exercise: reflecting and communicating.

Individual prototyping

Description: The participants are sitting around the group desk with the prototyping material in the middle and cardboard building platforms in front of them. They are asked to think of the aim of the workshop and their idea of Task 1, and to try to visualise this with the given material on the building platform. They may incorporate the object from the warm-up into the prototype if desired.

Aim: The aim of the individual prototyping is to create a reflection and visual representation of the participant's own perspective on the topic and/or Task 1. The created prototypes help to communicate the contributions to the group and serve as a foundation for the co-creation process. Main functions of individually created prototypes: reflecting, visualising and communicating.

Presenting individual prototypes

Description: Each participant is asked to present their prototype to the other members of the group, emphasising the relationship between their ideas and the topic of the workshop (See Figure A1).

Aim: The aim of this step is communicating individual ideas/contributions to the group, which serve as a foundation for the co-creation process.

Collaborative prototyping

Description: In the collaborative prototyping step the participants are asked to work together towards Task 2 based on their ideas from the individual prototyping. They should visualise their common ideas using the co-creation space in the middle of the table (See Figure A2).

Aim: The co-creation part of the workshop helps the participants to develop a joint approach to the topic of the workshop/Task 2 and is built on the reflected and visualised contributions of the individual prototyping step. Main functions of co-created prototypes: discussing, deciding and visioning.

Written reflection

Description: The participants are given a prepared reflection sheet with 2–4 questions and asked to reflect on their impressions of the prototyping processes.

Aim: The written reflection helps to record the individual experience of each participant and to avoid the opinions of individual participants getting lost in the discussion or certain experiences dominating the discussion.

Group presentation

Description: One participant per group is asked to present their co-created prototype to the other participants of the workshop. They should emphasise how they built them to address Task 2, how they incorporated the individual prototypes, and explain the different elements of the prototypes and the connections between them.

Aim: The participants learn about the ideas, supported by the visuality of the prototypes and collaborative approaches of the others.

Group discussion

Description: The participants are asked prepared questions regarding specific aspects of the topic of the workshop.

Aims: The group discussion is meant to identify drivers, actors and/or other aims of the workshop. The individual and co-created prototypes and the process of building them serve as a base for this discussion. Main functions of prototypes in group discussion: communicating, discussing and deciding.

Moderators' and facilitators' guides

Steps of the prototyping process	*Tasks of/text for moderator*	*Tasks of facilitators*
General tasks	• being the host for the workshop • main moderation • general time-keeping	• assisting the moderator • taking care of the documentation • taking care of the tables • answering individual questions at the tables

Object-related warm-up	• ‘Think of the topic of the workshop and choose a material from the table’ • ‘What appeals to you when you think of the topic of the workshop?’ • ‘After you picked your object, please come closer and explain to the others very briefly: What does the object represent in the context of the topic of the workshop?’ • ‘Please put the objects on the table.’ • Short discussion: ‘Where do you see linkages within this material picture?’	• One facilitator: Writing ideas on the whiteboard • One facilitator: When all objects are on the table, take a picture

Individual prototyping	• ‘Please think of the aim of the workshop What is your contribution to reaching Task 1? Please try to visualise this with the given material on your building platform. You can either incorporate the object from the warm-up into your prototype or not’
	• ‘Try not to talk during the next 30 min to not interrupt the thinking and thought process of the others’
		Try to make participants build; not too much discussion in this part
		• Take care of the documentation (pictures, recording, notes when something special)
		• Some questions that might stimulate the prototyping process (use carefully, try not to interrupt thoughts):
		  • ‘Where do you locate XYZ?’
		  • ‘What is your role in this?’
		  • ‘How are you contributing to XYZ?’
		  • ‘Does the contribution consist of one or several elements?’
		  • ‘Are they separate or connected?’
		  • ‘What stimulates or hinders your contribution?’

Presenting individual prototypes	• ‘Please explain your prototypes to each other within the group, emphasising the relationship between XYZ and the topic of the workshop’	• Try to give everyone the same talking time • Take care of the documentation (pictures, recording, notes when something special) • Each final individual prototype should be photographed • If someone is shy, try to point to specific elements of the prototype and ask for their meaning or ask questions from above • Listen to metaphors

Collaborative prototyping	• ‘Now that you have all these individual contributions, how could they be put together to answer Task 2? Please visualise your ideas using the co-creation space in the middle of your table’
	• Later: ‘You can deconstruct them or leave them as they are and use additional new material’
	• Do not interrupt too much what they would do on their own
		• Help the team put the material to the corners of the table to have an empty co-creation space
		• Take care of the documentation (pictures, recording, notes when something special)
		  • How do they place their individual prototypes in the co-creation space?
		  • The co-created prototype should be photographed at the end
		Some questions that might stimulate the prototyping process (use carefully, try not to interrupt thoughts and thought exchange between them):
		  • What would be a possible strategy to use the existing contributions to the vision?
		  • Do the different initiatives need to be connected? What might this look like?
		• Try to avoid broad and general discussions (they will come later), try to make participants build
		• Find one team member to present their co-created prototype

Written reflection	• ‘Please take a moment to reflect on what you have done during the prototyping processes and take notes on the participant reflection sheets’	• Answer upcoming questions
Group presentation	• ‘Please present your co-created prototypes (one participant per group) and explain how you worked in order to build them’ • ‘Describe your group prototypes. Explain very briefly the different elements and the connections between them’	• One facilitator: taking care of the documentation (pictures, recording, notes when something special)
Group discussion	• Ask the questions you prepared for the discussion • Five questions; each 5 min’ discussion	• One facilitator: taking notes on the whiteboard/flipchart • One facilitator: taking pictures
Close	• ‘Thank you for being part of this workshop!’ • Feedback: ‘Please share your thoughts on what we did, feedback, questions, comments, etc.’ • Check-out: ‘What was the most interesting outcome for you today? What do you take home from today?’	• One facilitator: taking notes on the whiteboard/flipchart • One facilitator: taking pictures

Questions that could be asked by facilitators during the prototyping to support the process

General questions on material and form

- What kind of material expresses your feelings?
- What is the shape of the material?
- What kind of surface suits most?
- What is the relationship of the size of the different parts?
- Does the colour and materiality have any special meaning?
- How could you implement value or quality to the material?
- Do you want to reflect the physical state of the material within your model? Etc.

Questions concerning task 1

- What is your first impression when you think of XYZ?
- What special characteristics/aspect/element do you want to build?
- How does X refer to Y?
- How could aspect XYZ be characterised?
- What is the overall goal?
- What is your role concerning Task 1?
- How could a specific standpoint, wish or conflict be prototyped with the material?
- How can this be represented by form, surface, texture, size, colour, material? Etc.

Questions concerning task 2, e.g., referring to team and personal role

- What kind of different roles/positions should be built?
- What is your role within your team and how would you describe it?
- What is the task your team is responsible for?
- What are the methods and tools (programs, materials) you use in your team?
- How would others describe your role?
- How did you come to the solution?
- How did the material help you?
- Is there a similarity between the different prototypes? Etc.

List of materials

This list serves as a suggestion. Not all materials need to be available. Further materials can be added or a selection can be made of, for example, particularly sustainable materials.

- thick A3 greyboards: 1 piece per participant
- sticky notes (A5, A6): 1 package per participant
- large sheets of wrapping paper/brown paper (as a basis for building on the table and for protection): 2 per table or as a roll
- cardboard cards: 1 pack per team
- tape: 1 roll per team
- wasi tape in five different colours
- white paper A4 and A3: 1 package in total
- coloured paper A4: 20 sheets per team

- pencils and thick markers in black and other colours: 1 per participant
- old cardboard (e.g., boxes, egg cartons)
- old plastic packaging (e.g., yoghurt pots)
- shears and/or cutters: 1 per team
- glue sticks: 1 per team
- side cutters or pincers (for wire): 1 per team
- ruler: 1 per team
- wool or raffia: 2 different colours per team
- plasticine (grey or other colours): 1 pack per team
- wooden blocks: 20 per team
- skewers or toothpicks: 1 package per team
- craft wire (sections) or pipe cleaners: 1 pack per team
- elastic bands: 20 per team
- old pieces of fabric
- cotton wool
- natural materials (e.g., bark, leaves, fir cones, twigs).

Note

[1]We are aware of the extensive literature on boundary objects and believe that a detailed analysis of the role of design prototypes as boundary objects would provide a valuable contribution, which we would like to develop in a future research project and a separate article. At this point, such an undertaking would be too extensive and lies beyond the scope of this article.

‘The ability to recognise complexity, without controlling and illegitimately reducing it, paves the way for dealing productively with limits of knowing.’

11.4. Article 4

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Collaborative design prototyping in transdisciplinary research: An approach to heterogeneity and unknowns

Daniela Peukert [a,*], Ulli Vilsmaier [b]

[a] Leuphana University of Lüneburg, Faculty of Sustainability, Universitätsallee 1, Lüneburg, 21335, Germany
[b] Leuphana University of Lüneburg, Universitätsallee 1, Lüneburg, 21335, Germany

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ABSTRACT

This paper provides insights into the practice of design-based interventions in transdisciplinary research and demonstrates how design prototyping can be made fruitful in processes of transformation and collaborative knowledge production. It shows how heterogeneous perspectives and stocks of knowledge can be related to each other and moments of integration generated by working with conceptual designs. Due to their open character, design methods are discussed as particularly promising when dealing with a high degree of complexity, uncertainties, and unknowns. After a characterization of design research and prototyping, common strategies of design research and transdisciplinary research for addressing heterogeneity and unknowns will be explored. This serves to frame the transfer of design practices to support integration processes in transdisciplinary teams. Using an example from a transdisciplinary case study in Transylvania, the implementation of design prototyping will be demonstrated and initial findings presented. Different integration dimensions from transdisciplinary sustainability research serve as a basis for investigating the epistemic, social-organizational, and communicative integration performance of design prototyping. For transdisciplinary research, design practices expand the methodical canon for working in heterogeneous teams and tackling uncertainty and unknowns in openness.

1. Introduction

Transdisciplinary research approaches complex problems of sustainable futures with high degrees of uncertainties and unknowns (Bammer, 2019) by incorporating heterogeneous perspectives and different forms of knowing and knowledge production (Bammer et al., 2020; Hirsch Hadorn et al., 2008; Mitchell et al., 2015), and by linking epistemic with transformative objectives (Vilsmaier, Brandner, & Engbers, 2017). This can lead to constellations of research teams, comprising representatives of different scientific and societal realms (Polk, 2015; Stokols et al., 2013). However, in order to bring heterogeneity and difference into fruition when tackling pressing complex problems, forms of research and their according methods also need to be diversified (Vilsmaier, 2018). A major challenge exists in grasping the multifaceted and often blurred phenomena of the future, which only become more sharply contoured when approached. This is accompanied by the challenge of achieving mutual, eventually shared, understanding of what is considered to be the problematic situation and subject of inquiry. This is particularly demanding when collaboration is envisioned between people who are situated in fields of knowledge and practice that are far away from each other, i.e., in broad interdisciplinarity (Klein, 2010) or in transdisciplinary research that involves expertise from different lifeworlds

* Corresponding author.
E-mail addresses: daniela.peukert@leuphana.de (D. Peukert), vilsmaier@leuphana.de (U. Vilsmaier).

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(Merçon et al., 2018), such as local initiatives, administrative units, and academic disciplines, as in the cases that underlie this article.

To enable mutual understanding, forms of collaborative knowledge production are needed that make differences in heterogeneous teams visible, utterable, and tangible (Vilsmaier, 2018). Therefore, it is necessary to recognize the limitations of any viewpoint and deploy epistemological and methodological tools that foster expression and allow translation to create the common among the different (Merçon et al. 2018). We have to acknowledge, however, that there is a fundamental incompleteness in understanding complex problems, as they are undetermined and open, and therefore "not predictable, regardless of the capabilities of our epistemological [and methodological] toolbox" (Grunwald 2007, p. 257). In order to adequately deal with such phenomena, openness is needed (Darbellay et al., 2014; Jacobs et al., 2018; Maguire, 2018)—overall, an attitude of openness for new discoveries and observations, and appropriate methodological approaches. "[O]penness of the future, […] is not an openness in an arbitrary sense but in the sense that shaping activities can and will have an impact on the further course of development" (Grunwald 2007, p. 257). The ability to recognize complexity, without controlling and illegitimately reducing it, paves the way for dealing productively with limits of knowing. A major challenge is to acknowledge that one's own positioning, one's own understanding, is always only temporary and must thus be understood as an intermediate step towards the next (Meyer & Peukert, 2020). Given these circumstances, methodical approaches to complex phenomena are required that promote an approximation of the unknown while maintaining an attitude of openness.

For that purpose, we have started to work with design methods in a series of transdisciplinary research processes that tackle sustainable futures. We chose design prototyping as it is a language of form and has the potential to mediate different conceptual realities, thought styles, and ways of knowing. Prototypes can be considered objects that "represent anticipated possibilities as tangible realities which can be acted upon" (Dickel, 2019, p. 13, own translation [o.t.]) and therefore help us to cope with the unknowns of the future. By addressing unknowns (Bammer et al., 2020), we describe a specific research conditions of complex sustainability problems that makes it difficult to anticipate possible futures. These conditions require a form of imagination that enables research into what is not yet tangible, which we explore with design prototyping. Here, a proximity to future studies emerges; its methods, for example techniques of modeling or scenario building, enable imagination and thereby make possible futures approachable. Former studies have already elaborated on similarities between scenario practices and design research, such as the role of narratives or iterative processes (Chermack & Coons, 2015; Selin et al., 2015; Steckelberg, 2015; Vervoort et al., 2015). Design prototyping can add to this literature by addressing possible futures and making them imaginable. As prototyping is a process in the making, i.e., materialized through individual and collaborative construction, it not only has the potential of revealing and mediating different perspectives and knowledges that are present among team members, but also of jointly creating shared ones. Thus, "[t]he prototype is both an epistemic object that enables learning in situ and a materialized promise of a realizable future" (Dickel, 2019, p. 9, o.t.).

This article approaches research into the use of design prototyping within transdisciplinary research processes from a perspective of design research. Understood here in expanded terms, design describes goal-oriented actions that transform existing states into desirable ones through different forms of creative expression (Simon, 1996), and thus carries a transformative moment. For this purpose, designers use conceptual designs to visualize ideas in a design process[1] . These conceptual designs have both a procedural, open character and a finalized quality that is grounded in the materiality of the object (Peukert & Vilsmaier, 2019). They thus materialize both as process and product. Ideally, conceptual designs provide a good sense of an idea, but also leave room for interpretations and further development. Within the conceptual design, different knowledge sources merge and manifest as a designed artifact (Cross, 2001; Lawson, 2005). The conceptual design thus supersedes "theory and practice and enables not only a new reality but also new insights" (Aicher, 2015, p. 195, o.t.). In the design context, conceptual designs can take up a variety of forms, e.g., sketches, drawings, mock-ups, prototypes, computer-aided design (CAD) representations, or renderings (Bürdek, 2015). Despite these apparently different outward forms, conceptual designs have in common that they are manifestations of an idea, produced in an iterative process of thinking and doing, "containing elements of future, uncertainty, and provisionality" (Meyer & Peukert, 2020).

The aim of this paper is to develop a conceptual basis for the targeted use of design prototyping as a method of boundary-work (Klein, 2014; Leigh Star & Griesemer, 1989; Wyborn, 2015) and knowledge co-production in transdisciplinary research processes. Departing from an elaboration of our understanding of design research and transdisciplinary research, common strategies of the research fields in addressing heterogeneity and unknowns will be identified and examined. This is followed by a description of the design prototyping method and its application in a transdisciplinary case study. First observations and insights are shared, and the method is illuminated according to its transdisciplinary and transformative characteristics to assess how it can be implemented within transdisciplinary research. A concept of diverse dimensions of integration taken from transdisciplinary sustainability sciences forms the basis for examining the integration performance of design prototyping, which is discussed as an opening practice with knowledge-generating and mediating qualities in addressing the uncertainties and unknowns of complex problems.

2. Design prototyping in design, design research, and transdisciplinary processes

Design as a profession has gained importance significantly since the Industrial Revolution in the mid-nineteenth century and the commencement of machine-based production in factories (Bürdek 2015; Rodgers & Milton, 2011). At that time, the design of form had

[1] We refer to a 5-phases design process according to Bürdek (2015), Dubberly (2004) and Martin & Hanington, 2013 that comprises a specific conceptual phase, as will be explained in more detail in Chapter 2. In addition to this framing of a design process, there are others, such as in Design Thinking (Meinel & Leifer, 2011) or the "Double Diamond" process of the UK Design Council (UK Design Council, 2019).

become detached from manual production and became the task of the designer. This task has always been interdisciplinary, working at the intersection with other professional fields that were part of the production process, such as marketing, engineering, construction, distribution, and sales (Julier, 2017). Through industrial and technological development, the discipline of design has strongly diversified. Today, it includes a diverse spectrum of sub-disciplines in areas such as fashion, graphics, communications, packaging, interfaces, services, interiors, and textiles (Erlhoff & Marshall, 2008). As a discipline situated between science, art and craftsmanship, design is strongly influenced by social, political, and societal developments, as well as creative trends, as seen in, for example, the functionalist approach of modernism (Bürdek, 2015).

The term design stems from the Latin *designare*, which means "to designate, to determine, to represent in outline, to reconstruct" (Pfeifer, 2010), and subsumes all aspects of the process-oriented design practice, like shaping, planning and conceptualizing, as well as different sub-disciplines of design and engineering and the object itself. Design activities like planning and conceptualizing are understood as an expanded concept of design, whose potentials are explored here in the context of transdisciplinary research. "To design implies the entire process of strategy, planning, development and production. The expanded design concept oscillates between 'design doing' and 'design thinking'" (Banz, 2016, p. 11, o.t.). Design doing primarily describes the making and practice of design, while design thinking grasps the processes of planning and thought within design. The convergence of design thinking and creative action thus reveals the actual meaning of design: "Design means relating thinking and making to each other" (Aicher, 2015, p. 11, o.t.). The term design thinking is discussed differently in two fields of discourse (Johansson-Sköldberg et al., 2013; Laursen & Haase, 2019; Mareis, 2011). In the discourse on design research, design thinking or designerly thinking has been used since the 1960s to discuss how thinking and doing are intertwined in design. Johansson-Sköldberg et al. (2013) distinguish five different theoretical approaches to design thinking: the creation of artifacts, reflective practice, a problem-solving activity, a way of reasoning, and the creation of meaning. The concept of design thinking has also received considerable attention in the management literature since the early 2000s Here, the term is primarily understood as a human-centered innovation method for solving complex problems that can be carried out as a process by anyone, including non-designers, based on how designers think and work (Carlgren et al., 2016; Brown, 2008; Kimbell, 2011). The understanding used in this paper should be taken as being in the tradition of the design research discourse.

Over the course of time, the focus of design work has moved away from products and expanded to include goods, services and identities, interfaces, networks, and projects, towards the shaping of discourses in a "trajectory of artificiality" (Krippendorff, 2011). The practice of design, deployed as an act of planning and supported by the visualizing power of design methods, so as to make it experienceable for others, comes to be included not only in designing products but also within other areas such as, for example, political and social processes (Escobar, 2018; Fry, 2011; Manzini, 2015; Papanek, 1985). This also detaches design from the physical object—especially from the designed artifact, with its aesthetic and functional demands that go hand in hand with the design of forms—and focuses on the process of designing, regarding it as a procedural activity with transformative potential. Despite this detachment of design from the physical object, and the application of design practice and design methods in other areas, the interweaving of design doing and design thinking remains a specific quality of design.

Distinguishing the concepts of design research from those of design practice and theory serves to understand the different areas of design application. Design practice describes all creative- and conceptual-stage processes of design (Rodgers & Milton, 2011). Design theory subsumes the theoretical bases and concepts of design, such as semiotics, semantics, or aesthetics (Bürdek, 2015). The term design research refers to all practical scientific activities that focus on the perspective of knowledge generation within design theory and practice (Rodgers & Yee, 2014). The understanding of design research underlying this contribution is based on the concept of "research through design" (Frayling, 1993), which was originally conceived by Christopher Frayling and later developed further by Alain Findeli (1998) and Wolfgang Jonas (2012). Frayling originally distinguished "research into," "for," and "through" design (1993, p.5); Jonas expanded upon this triad by rephrasing "research into" to "research about" design (2012, p. 21/22). According to these authors, research about design refers to a mode of looking at design from the outside, as in design history. Research for design includes cognitive fields that are subservient to the design process, like market research or user observation. Research through design describes a concept that engages in research by applying or using creative design methods such as design prototyping. The design researcher is thus directly involved in the research process and plays an active role in shaping it. This image of design research as research through design, and an expanded understanding of design as a creative process oscillating between thinking and doing, has great potential to be applied in transdisciplinary research.

Conceptual designs and prototypes play an important role in research through design approaches and serve to externalize, visualize, examine, reflect on, and discuss thoughts and ideas (Peukert & Vilsmaier, 2019). In their tangibility they differ from spoken word and written text. They are used in various phases of a design process for communication and verification purposes. A design process can roughly be divided into five phases: (i) research, (ii) analysis, (iii) concept, (iv) draft, and (v) implementation (Bürdek, 2015; Dubberly, 2004; Martin & Hanington, 2013). Phases three to five especially go through several iterative loops. Due to the field's interdisciplinarity, a variety of methods that are also applied in other fields are implemented in design processes (Martin & Hanington, 2013). The authors define design methods as all methods within a design process, whereas conceptual design methods are only those specific creative approaches that include both two- and three-dimensional artifacts. Therefore, they can be called design specific. This differentiation is useful, because it frames conceptual designing as an independent practice and not just part of a process towards a final design. In this way, conceptual designing in general, and design prototyping in particular, can be detached from the design context and interrogated for their integrative and imaginative character, so as to be implemented more purposefully when dealing with the complex problems of sustainable futures.

The specific conceptual design method we look at here is design prototyping, which describes the construction of small conceptual designs whose development stage is located somewhere between mock-up and prototype (Hallgrimsson, 2012). Mock-ups are small models made from inexpensive materials that serve to verify a design by employing the first step from sketch to three-dimensional

tangible form. The aim of mock-ups is to provide a quick visualization of the conceptual design, or to verify important functions such as proportions, shape, ergonomics, or technical mechanics (Exner et al., 2015). They may include the entire design or only parts of it. Mock-ups are a communicative and discursive medium that can be adapted and developed further in meetings between users and designers or with a design team (Sanders, 2013; Sanders & Stappers, 2014; Stappers, 2013). Prototypes are one step further in their development. Depending on their level of detail, they range from conceptual models that verify aesthetic and ergonomic attributes, through true-scale models that verify usage, to functional models with the characteristics of the later serial model (Moeller, 2008). Design prototyping uses various inexpensive materials such as paper, cardboard, plastic, or household items, like sponges, foil, or wooden skewers. From these, the designing person can create a three-dimensional representation of the idea, or a certain aspect of the idea, in a short amount of time, individually or in a team. In principle, any person without specific technical knowledge or particular skills can carry out design prototyping, and all materials and prototyping techniques are allowed. The resulting design prototypes do not need to fulfill any aesthetic or functional requirements, but should rather serve to reflect, verify, visualize, and communicate an idea (Peukert, Lam, Horcea-Milcu, & Lang, in press). The reason we chose design prototyping over a variety of different conceptual design methods lies in the three-dimensional quality of the resulting designs. The prototypes allow for localization and movement in space, and views from different perspectives. Furthermore, design prototyping processes can be carried out both individually and in a group, plus the elements can be deconstructed and rearranged and serve as a basis for discussion and collaborative building.

Applying design prototyping in transdisciplinary research differs in some ways from the use of prototyping in design disciplines. The first point concerns the role of the designer. When applying design prototyping, the designer does not necessarily do any designing themselves, but may be in the role of a moderator or facilitator who provides the space and tools, and guides and supports the participants in the prototyping process. Furthermore, the context is detached from design or a product orientation, which also leads to more heterogeneity, as transdisciplinary team compositions can be far more diverse than those of product development teams. Moreover, the focus of design prototyping is on exchange and mutual learning, and not on results or the verification of aesthetic-formal features, technical functionality, or user acceptance. Finally, the use of design prototyping for collaboration makes a significant difference. Compared with the design disciplines, where prototypes are built by the designer or model maker, design prototyping in transdisciplinary research is more closely linked to the research setting and the problem of concern. Moreover, it is strongly embedded in the process and is therefore in itself only an intermediate step in the overarching research process. However, despite the differences between the two fields of application, there are similarities with regards to the qualities inherent in prototypes, such as their process-object, visual-tactile, spatial, and metaphorical qualities (Peukert, Lam, Horcea-Milcu, & Lang, in press). They can be used to communicate and discuss ideas, and translate different ways of thinking. Their iterative, open and playful character stimulates imagination and creates space for trial and error without closing down further development.

3. Strategies of design-based transdisciplinary research to approach heterogeneity and unknowns

This contribution is based on a research mode of critical transdisciplinarity (Vilsmaier, Brandner, & Engbers, 2017; Meyer & Vilsmaier, 2020). At the level of practice, it strongly relates to problem-oriented discourses as developed in transdisciplinary sustainability sciences (Jahn et al., 2012; Lang et al., 2012) and takes up the joint production of knowledge with actors from different societal realms. With regard to the general structure of such research processes, it is based on the steps of problem constitution, collaborative research through co-production of knowledge, and its re-integration into societal and scientific fields (Hirsch Hadorn et al., 2008; Jahn et al., 2012; Lang et al., 2012). An essential aspect here is the team composition, i.e., the involvement of different actors from research and societal practice, in order to deepen insights due to the diversity of perspectives and to transform the situation of concern through collaboration. Along the same lines as critical interdisciplinarity (Klein, 2010), critical transdisciplinarity acknowledges the value of different types of knowledge that are gained in different ways, taking into consideration the different epistemic qualities and related quality criteria. At the same time it is constantly “interrogating the dominant structures of knowledge” (Klein, 2010, p. 23) and searching for new research alliances to tackle complex problems. In contrast to science-driven transdisciplinarity, critical transdisciplinarity aims to create in-between spaces in which “the own, the uncertain and the difference can perpetually be fathomed, interpreted and negotiated” (Vilsmaier, Brandner, & Engbers, 2017, p. 174). In these spaces “[e]xisting structures, power relations and dependencies can be suspended—at least for a situational episode—when discrepancies are articulated and thereby made tangible” (Vilsmaier, Brandner, & Engbers, 2017, p. 174). Thereby, both epistemic and transformative aims can be pursued alike.

Such transdisciplinary research spaces are constituted in difference and created through integration. For analysing the integration of diverse ways of knowing, acting, and being (Vilsmaier, Brandner, & Engbers, 2017), a distinction is made between epistemic, socio-organizational, and communicative dimensions of integration (Jahn et al., 2012). Epistemic integration refers to the identification and linkage of different scientific and non-scientific bodies of knowledge (Förster et al., 2018; Pohl et al., 2021). The different interests and operating modes of those involved in the process are laid bare and reconciled through the level of socio-organizational integration. The dimension of communicative integration addresses the finding of a joint language as the basis of mutual understanding. For this purpose, different (technical) terms, meanings, and communicative practices need to be identified and related to each other. As a conceptual and analytical framework for the implementation of and research into integration within transdisciplinary processes, this dimensional triad has proven to be useful. To enable cooperation between different actors and the linking of heterogeneous ways of knowing, acting, and being, explicit integration abilities are needed. Further, it requires an expanded repertoire of methods, so as to enable collaborative knowledge co-production within heterogeneous teams to create conditions for joint thinking and doing, and to promote openness in approaching the uncertain and unknown.

In what follows, we will elaborate on the commonalities and connecting elements of design and transdisciplinarity to lay the

ground for incorporating design prototyping into transdisciplinary research. Both transdisciplinary research and research through design can be considered as modes of a new understanding of research and knowledge production—one that emphasizes unknowns and provides strategies to deal with uncertainty (Hirsch Hadorn et al., 2008). Both fields deal with complex issues that are highly context dependent and unique (Alexiou & Zamenopoulos, 2008; Beckett, 2020; Bammer et al., 2020; Popa et al., 2015), oscillating between the ideographic of the specific phenomenon and the larger, general knowledge (Krohn, 2010). In many cases, subjects of concern are "wicked problems" (Buchanan, 1992; Klein, 2014). Such problems are difficult to tackle: they cannot be fully defined because the conditions of their origin are always incomplete and constantly changing (Rittel & Webber, 1973). This fundamental incompleteness forces researchers in both fields to navigate and assert themselves in uncertain and unknown territory. These conditions require researchers to attain methods and competencies, such as being able to recognize that the result or conceptual design can always only be seen as an interim stage in an iterative development loop. However, people often react to a state of the unknown with uncertainty (Grunwald, 2007), which means being insecure about the unknown and their own abilities.

An approach to unknown futures, while maintaining openness, is iteration. Both research modes, transdisciplinary research and research through design, are characterized by a strong orientation towards processes that are run through iterative loops. For this purpose, the processes are often divided into several steps. Wolfgang Jonas assigns design processes to a larger macro-cycle of analysis, projection, and synthesis, which is run through repeatedly (Jonas, 2006). In design thinking, different steps of understanding, observing, defining a point of view, brainstorming, and developing prototypes are run through repeatedly (Meinel, Weinberg, & Krohn, 2015). Likewise, the ideal process model of a problem-solving transdisciplinarity (Jahn et al., 2012; Lang et al., 2012) also encapsulates various procedural phases. Here, the steps of problem constitution, knowledge co-production, and knowledge re-integration are differentiated, which are also conducted as recursive processes (Hirsch Hadorn et al., 2008; Lang et al., 2012). The circular character of both research modes means that the results of problem solving in both design and transdisciplinary processes transform the conditions for each subsequent loop by iterating between thinking and doing, or between different team constellations. Here, a fundamental transformative moment and openness for research development is incorporated (Meyer & Peukert, 2020). At the same time, models of both fields show how strongly they are anchored in a pragmatic and linear understanding of problem and solution. This may suggest an all too simplified logic, which is however not elaborated upon further at this point (see Meyer & Peukert, 2020). Design prototyping can be realized as an iterative step-by-step approach to the unknown, as through the intrinsic entanglement of thinking and doing, exploratory access to the problem of concern is created.

4. Designing sustainable regional futures in Southern Transylvania, Romania

4.1. Case description

In the research project on sustainability transformations, design prototyping has been used in a number of workshops with different groups and in different phases of the transdisciplinary research process. To illustrate the procedure of design prototyping and exemplary application, we provide an example of a workshop in Transylvania, which was conducted as part of the research project Leverage Points for Sustainability Transformation". A detailed description of the procedural approach (incl. agenda, moderators' and facilitators' guide and material list) and empirical analysis is provided in Peukert, Lam, Horcea-Milcu, & Lang, in press and Peukert (in preparation). The aim of the transdisciplinary case study was to enable and support sustainability transformations in the rural region of Southern Transylvania. It has been grounded in the results of a preceding project, where a future vision for the region, set in the year 2043, was conceived in a collaborative scenario process (Hanspach et al., 2014). The exemplary workshop for the application of design prototyping was implemented in September 2016 and gathered 30 participants working for different non-governmental organizations (NGOs) in the region (e.g., nature conservation, supporting small-scale, traditional or organic farming, agro-tourism and ecotourism, rural community development, cultural heritage conservation) and scientists. It aimed to identify existing sustainability initiatives and

Fig. 1. Example of a design prototype that illustrates an initiative's individual contribution (task of individual prototyping – step 1).

their contribution to the future vision, support trust building, and develop initial ideas for possible collaborations across various institutions.

For this task, design prototyping was implemented in two steps: in an individual prototyping phase single participants as representatives of involved initiatives were asked to reflect upon their existing contributions to the future vision and to prototype this contribution with the given materials (see Fig. 1). The first image shows one prototype of the individual prototyping step: the representative of the specific initiative has built a traditional gathering of craftsmen on chairs (symbolized by figures on foam cubes), in the middle of which are their tools. These kind of gatherings are supported by the initiative as a form of cultural heritage conservation. The resulting prototypes of step 1 were subsequently presented and explained to the other members in small groups. In a second step the participants were asked to discuss a joint procedure towards the vision on the basis of the individual contributions, and to build it by incorporating the existing prototypes and materials (see Fig. 2). The second image shows one group discussing a joint approach for the initiatives using their individually created design prototypes. The participants negotiate using existing material, rebuilding and adding to it, and thus create a new, common prototype. Based on the design prototyping experiences, a plenary discussion was moderated to identify the drivers and barriers that promoted or hindered the achievement of the vision. The group also discussed the further needs of the organizations to reach the common approach they developed in the design prototyping process, as well as missing actors, knowledge, and political and organizational structures.

4.2. Observations and insights

The main challenges of this workshop were rooted in the fact that the participants work for different NGOs in Transylvania that pursue different, and partially contradicting, objectives and interests in the region. By talking about the different interests, promoting mutual understanding, and defining a common goal, participants had to overcome their inner hurdles and prejudices. Furthermore, the NGOs are unevenly equipped and networked, so power differences had to be balanced out and existing tensions and misunderstandings addressed.

For analyzing the integrative character of design prototyping we use the different dimensions of epistemic, socio-organizational, and communicative integration introduced by Jahn et al. (2012). When looking at design prototyping at the level of epistemic integration it was observed that participants negotiated their own and others' thoughts, with the help of the conceptual designs, in a reflexive manner. Ideas—or, as in the case of the case study, initiatives of an organization—were visualized in individual and collaborative construction processes. The prototyping material invited the participants to translate their ideas into material- and object-related metaphors. Thus, underlying knowledge can be broached and verbalized, but also be presented in alternative ways to linguistic expressions. By being thrown back upon less established and rarely used terms of expression, i.e., a language of form via three-dimensional visualizations, participants with different professional backgrounds and varying hierarchical positions were brought to a similar ability level. Existing differences that emerged within the heterogeneous teams were balanced. The conceptual designs developed during design prototyping enabled the exchange, communication, and discussion of participants' perspectives on the current state of the situation and their visions for a sustainable future with others. Communication between those participating in the process was mediated via the conceptual designs. Potential differences were leveled through the use of visualization, thus enabling stronger integration at the level of communication. In this example, the aspects of social-organizational integration were addressed as participants representing their organizations individually visualized existing activities and exchanged views on different interests before conjointly searching for potential future collaborations and structural synergies that could be shared.

A first observation that emerged from working with design prototypes within transdisciplinary processes was that dimensions of integration proved to be very useful as instruments for the planning and analysis of integration. At the precise moment of practical

Fig. 2. Participants discuss a common approach towards the vision for their various initiatives on the basis of the material and individually created design prototypes (task of collaborative prototyping – step 2).

work design prototypes have a strongly unifying effect, making the separation of different dimensions of integration barely possible. First insights from ongoing empirical analysis show that the prototypical work with conceptual designs was very well received by the participants, across all disciplines and practices, and viewed as positive for enabling communication and collaboration (see Peukert and Vilsmaier, 2019). It was observed that participants who were otherwise unlikely to do so engaged in conversation with each other, although occasionally certain limitations were noted due to the choice of means of expression.

These experiences indicate that the methodological use of design prototyping in transdisciplinary research has an explicitly mediating character, which emphasizes the boundary role (Klein, 2014; Star and Griesemer, 1989; Wyborn, 2015) of the designed artefacts. One's own and third-party perspectives are mediated and made comprehensible when working with design prototypes. It is precisely this mediating intervention into the transdisciplinary process that illustrates the transformative character of conceptual designs and that takes effect at all levels of integration. However, it also became apparent that in order to embark on the long journey towards sustainable futures for the region, and to negotiate the complex issues that arise in the process, multiple forms of openness are needed (Darbellay et al., 2014; Jacobs et al., 2018; Maguire, 2018). In this case study these have been openness to the different perspectives and interests of actors in the region, to the preconditions of trust building in political or funding structures, and to a future that includes changing social, political, and economic conditions to enable sustainable regional development. Here, design prototyping supports openness in three ways. First, at the level of the material: the flexibility to build any artefact with it, its modifiability, its lack of predetermined use, and openness to interpretation, invites the free visualization of ideas. Second, openness at the level of the design prototyping process allows for flexible adaptation to the overarching research process, case study context, and research question. And third, openness at the level of the design prototypes themselves, which allows for multi-layered interpretation, a connective communication of ideas, and continuous development, as design prototypes are open for modification and therefore never finished. The inherent character of openness of design prototyping contributes to the promotion of knowledge co-production through integration. What emerges is a co-produced artifact that may serve as a core element of boundary-work and starting point for rapprochement and mutual understanding, while at the same time incorporating differences and resisting them.

5. Conclusion

This paper lays the conceptual foundation for the application of design prototyping in transdisciplinary research and the use of design methods with an inherent openness to address unknowns and uncertainties when dealing with complex phenomena. It provides initial insights into design prototyping as a practice of boundary-work and knowledge co-production in transdisciplinary research processes and into how the application of this method can create structures for integration in heterogeneous teams. After positioning design prototyping in design and design research, common strategies of design research and transdisciplinary research for approaching heterogeneity and unknowns were explored in order to outline the transfer of design practices to support integration in transdisciplinary teams. We have oriented ourselves on the distinction of epistemic, social-organizational, and communicative dimensions, and analyzed to what extent these different dimensions of integration can be addressed through conceptual design practices as design prototyping. It could be shown that working with prototypes is effective in all integrative dimensions and that design-based interventions can relate to and combine different dimensions of integration. However, it seems important to expand the integration triad with a cultural dimension (Vilsmaier et al., 2015, Vilsmaier, Brandner, & Engbers, 2017). Working in heterogeneous teams exposes both differences in epistemic and knowledge cultures of the involved scientific disciplines and societal partners and differences of varying cultural practices and intercultural settings, which should be explicitly addressed in integration processes.

Design prototyping expands the methodical repertoire of transdisciplinary research. In comparison with other methods used in transdisciplinary research processes, design prototyping has specific qualities that are characterized by their inherent process character on the one hand, and their object status on the other. Prototypes are both becoming and already complete. The visual-tactile quality, tangibility, and manipulability of design prototypes enables a specific discussion with the object and further common development. Their spatial location allows the negotiation of different perspectives with them. As a material form of expression and language of form, they complement spoken language and text and have their own metaphorical quality. The playful character of the design prototyping process stimulates imagination to envision possible futures. Due to the iterative procedure the design remains open for further development and thus for rapprochement with the uncertain and unknown. Prototypes enable the epistemic, communicative, and social-organizational integration of involved participants and contribute actively to the collaboratively produced, transformative knowledge required for achieving sustainable futures. As an addition to linguistic expressions, design prototypes are used in the collaborative practice of heterogeneous teams to bridge varying communicative capacities, epistemic cultures, languages, and methodical practices. Consequently, as tools, design prototypes fulfill even more functions: through and with them, a thought can be developed, different ways of thinking can be translated, ideas reflected upon and communicated, visions elaborated upon, and decisions made. The different qualities and characteristics of design prototyping enable the unknown to be materialized in the object and the stimulation of imagination, thus approaching the unknown and making it accessible and tangible.

We see a need for further research into the use of conceptual design methods and their integrative potential, particularly with empirical data analysis to illuminate the process and effect of prototyping more in depth, and evaluations of the prototypes themselves. The latter especially may represent a major methodological challenge, as the analysis of artifacts consists of methodologies that are substantially less elaborated upon in comparison with the analysis of text and images. "While many of these [qualitative social research analysis methods] (in particular interview or text analysis based methods) have long been the subject of intense debate, the analysis of man-made materials (as a distinct form of artefacts) has tended to live a shadow existence, …" (Froschauer & Lueger, 2016, p. 1). This requires an in-depth examination of the epistemic qualities of prototypes, such as the questions, for example, to what extent they are self-explanatory, or require a description; what model characteristics they might have; to what extent they can be interpreted as

metaphors; and in what form codes are inscribed into them that will later need to be decoded. It is also important to shed light upon the implementation of further conceptual design methods beyond prototyping, and to find out in which phases of a transdisciplinary process conceptual designs can be used and which functions they would fulfill. For the practice of transdisciplinary research, but also for research on transdisciplinary, integrative, and transformative processes, design practices open up a promising expansion of the methodical canon of working in heterogeneous teams in substantial ways. Their characteristic of intertwining design thinking and design doing in an iterative manner generates a structural openness, which we consider to be of great value when addressing complex problems of sustainable futures that are characterized by uncertainties and unknowns. Design prototyping enables an alternative entry route into a necessary and deeper understanding of how the generation of collaborative knowledge and integrative epistemological processes take place. "The production and reception of prototypes is thereby transformed from an exclusive expert activity to a public social practice," (Dickel, 2019, p. 9, o.t.) as could be shown in our example. Design prototyping is promising for exploring unknown territory. It creates a space that lies on this side of every linguistic state, but beyond familiar research practice, which can constitute itself as a common starting point for heterogeneous teams, tackling uncertainty and unknowns in openness.

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Declaration of Competing Interest

The authors report no declarations of interest.

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‘When working with design prototypes, complex issues have to be broken down, represented with the help of material and thus simplified and translated. This translation into the material, breaks down disciplinary thinking and language – as the visual-haptic is also a form of expression in its own right – but one that transcends disciplines.’

11.5. Article 5

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Paper Manuscript (7693/8000 words)

Design-based approaches to collaborative knowledge production in transdisciplinary research

Daniela Peukert

Introduction

Current problem situations in the world and in particular in the field of sustainability are complex and often accompanied by uncertainty and unknowns (Bammer 2020; Grunwald 2007). Transdisciplinary research tries to deal with this complexity and uncertainty by including different perspectives of people coming from different disciplines, life-worlds, and cultural contexts, with their specific forms of knowing and bodies of knowledge (Hirsch Hadorn et al. 2008; Horcea-Milcu et al. 2020; Merçon et al. 2018; Mitchell et al. 2015; Polk 2015;). The creation of a multi-perspectivity to address complex problems and the resulting multi-layered heterogeneity brings with it a variety of challenges in collaborative work: for example, different forms of communication (e.g., different mother tongues or specialist languages), unequal power distributions, or diverging epistemic approaches (Author et al. 2021; Freeth and Caniglia 2019; Fritz and Meinherz 2020). The integration of different forms of knowing and bodies of knowledge as well as collaborative forms of knowledge production seem particularly significant for the core of scientific work and transdisciplinary processes for sustainability (Hirsch Hadorn et al. 2008; Jahn et al. 2012; Klein et al. 2001; Lang et al. 2012; Pohl et al. 2008).

The term knowledge co-production[1] describes the joint production of knowledge by different actors, including non-scientific actors (Lang et al. 2012; Hemström et al. 2021; Polk 2015; Pohl et al. 2010). This understanding goes back to authors such as Gibbons et al. (1994), who were looking to describe a changing science system with the term “mode 2.” In addition to the primary understanding of the involvement of different actors, however, this article also considers the social situatedness (Haraway 1988; Jasanoff 2004) of knowledge production. Furthermore, knowledge is seen as something linked to entities, but produced and negotiated through people. Based on Norström et al. (2020), knowledge co-production is understood as *“iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future”* (ibid., p.2). They also describe four principles of collaborative knowledge production in sustainability research, which are “context-based, pluralistic, goal-oriented and interactive” (ibid., p.3). This means that the process should be situated in the specific context, that multiple ways of knowing and doing are recognised, that challenge-specific goals are clearly defined, and that learning and engagement are active and ongoing.

[1] Used synonymously with collaborative knowledge production throughout this paper.

A second term that is often used in connection with collaborative knowledge production is integration. In transdisciplinary research, integration is described as the central methodological and cognitive process (Defila and di Guilio 2014; Jahn et al. 2012; Pohl et al. 2008) to establish novel connections between former unrelated entities (Jahn et al. 2012; Pohl et al. 2021. According to Pohl et al., *"integration is an open-ended learning process without pre-determined outcomes"* (2021, p. 23). For Jahn et al. (2012), integration is complemented by the practice of differentiation and divided into several dimensions: epistemic, socio-organisational, and communicative integration. Both terms are often used in parallel and synonymously, but they differ and complement each other. While knowledge co-production describes a goal for different entities to work together, the term integration provides a first indication of how this co-production can take place, namely by interlinking these entities (Pohl et al. 2021).

However, it remains unclear what this linkage can look like in very practical research terms. Furthermore, knowledge co-production and integration in heterogeneous teams brings up specific challenges. This is where existing methods for group negotiation processes, strongly based on language and text, reach their limits (Heinrichs, 2018; Muhr, 2020). To fill this gap, design-based methods can be used. They expand the mode of language and text to include the visual and haptic dimension. Creative and design-based methods are advanced as promising when it comes to addressing the challenges of knowledge co-production and dealing with the uncertainty of complex sustainability problems (Author and V. 2021; Förster et al. 2018; Pearson et al. 2018; Sangiorgi and Scott 2014). In this article, we will look at a specific design-based method, design prototyping, and its application to knowledge co-production in transdisciplinary processes. Design prototyping is a method for individually or collaboratively developing and visualising ideas by constructing small two- and three-dimensional models, which can then be discussed and revised (Author et al. 2021; Berglund and Leifer 2013; Exner et al. 2015; Sanders 2013; Sanders and Stappers 2014; Stappers 2013).

The aim of this paper is to highlight specific qualities of design prototyping and its emerging artefacts, to show how these influence collaborative knowledge production and integration using exemplary case studies, and to draw conclusions about how these advantages can be used for collaborative processes with heterogeneous groups in inter- and transdisciplinary research settings. To this end, the article is structured as follows: first, the research context of the transdisciplinary case studies and workshop settings is described. Then, it is shown which data were collected to serve as a basis for the analysis. Second, the methodological approach of analysing a design prototyping dataset with qualitative content analysis, artefact analysis and the triangulation of both methods is presented. Third, the results of the analysis and specific qualities of design prototyping are provided. This is followed by a discussion of the methodological approach and the results as well as the implications of the findings for knowledge integration and co-production in heterogeneous teams and for addressing uncertainties of complex problems. Finally, conclusions are drawn for the use of design-based methods in transdisciplinary research as well as their analysis, and the need for further research is outlined.

Method of analysing design prototyping

Research context and data selection

The design prototyping method was used in the transdisciplinary research project "Leverage Points for Sustainability Transformations" (LP) (LP 2019), based at Leuphana University in Lüneburg, Germany. The project comprised a team of 23 international researchers and took place from 2015 to 2019 (for detailed workshop and project description, see Author et al. 2021). The aim of the project was to find within three realms (ReStructure, ReThink, ReConnect) deeper leverage points (Meadows, 1999) for sustainability transformations (Abson et al. 2017). The project included two place-based transdisciplinary case studies: one in Lower Saxony, Germany and one in Southern Transylvania, Romania (Fischer et al. 2019). The aim of each of the two case studies was to achieve with local actors and conditions sustainable development for the regions. The transdisciplinary work within the project included 23 workshops (10 in Lower Saxony and 13 in Southern Transylvania) with researchers and local actors. Design prototyping was used for different purposes during the project: interdisciplinary team building, transdisciplinary visioning, visioning with a specific local actor group, and interdisciplinary sharing, disseminating and discussing of preliminary research results (Author et al. 2021). The processes were recorded using pictures, audio, video, questionnaires, and observation protocols.

The empirical data for this paper come from two selected workshops that showcase the application of design prototyping in two different collaborative situations within a transdisciplinary research process (see also Table 1). The two workshops represent different phases of the project and each of the Leverage Points case studies. They serve to compare and contrast because one was interdisciplinary and one transdisciplinary, and in one only individual prototyping was done and in the other individual and collaborative prototyping were performed.

Table 1 Overview of selected workshops from which data were used for the analysis

Workshops	**A: LP Team Workshop, Lüneburg**	**B: LP Case Study Transylvania, Romania, NGO Workshop**
Collaborative research activity	Interdisciplinary team building	Transdisciplinary visioning
Guiding question	How to bring together local needs, own, and group research? How to get to know each other and their research interests?	How to bring together the work from different initiatives and make them visible?
What was built during design prototyping?	In four individual steps: the case study area, the research project, the personal research, and potential connections	In step one individually: contribution of organisation to the shared vision; in step two collaboratively: common pathway to the shared vision
Goals of workshop	Reflecting connections to case study area, work package, and own work. Discover the connecting potential.	Visioning about future of Southern Transylvania, reflecting own contributions, discussing joint contributions, formulating of a guiding question for the further project
Participants	Researchers with different disciplinary backgrounds (e.g. law, ecology, sustainability science, geography, economy)	Local actors (scientific and non-scientific) working in NGOs on nature conservation, cultural heritage conservation, supporting small-scale, traditional or organic farming, agro-tourism and ecotourism, and rural community development
No. of participants	11	28
Practices of the involved participants	Producing research	Working for the purposes of the NGOs

Within workshop A design prototyping was used as an interdisciplinary team-building technique for the LP project team. The overarching aim of this workshop was to find out about how to connect local needs, own and group research, and to get to know each other personally and in terms of respective research interests. Workshop B took place in the Romanian case study area, involving regional stakeholders of non-governmental organisations (NGOs) working in the area. The aim was to identify the NGO contributions to a future vision, to develop initial ideas for cooperation between the various NGOs, and to support further trust building (Lam et al. 2020). In both workshops, the production of design prototypes served to aid reflection, discussion and communication (Author et al. 2021) on specific questions around the case studies and knowledge co-production. The process of constructing the design prototypes was time-limited and facilitated. The materials for their production were provided by the organisational team and selected according to criteria such as low predefinition, malleability, flexibility, material diversity, etc. (for material list see Author et al. 2021). The production process and the resulting prototypes are the central elements of the design prototyping process and thus also form the core resource for answering the research question on the qualities of design prototyping. The selected data provide a representative insight into the application of design prototyping within two transdisciplinary processes. They represent different purposes of use, and provide a comprehensive

reflection of the process and the resulting artefacts,[2] so that an analysis of the qualities of design prototyping can be carried out on a sufficiently large amount of data.

For the analysis of design prototyping, the following data were analysed: audio recordings of the complete workshops (i.e., both the production phase and the phase in which the design prototypes were presented by their producers) and their transcripts, photographs of the prototyping process, and final prototypes. The participants' answered questionnaires and the observation protocols were used to support the evaluation, for example by clarifying the participants' motives for choosing materials, or by providing background information on organisational or interpersonal conditions of the workshops that had an impact on them but could not be captured in the data material of audio recordings and photographs.

Method selection and triangulation

In order to be able to comprehensively analyse both the production process and the final prototypes, and thus gain a holistic understanding of design prototyping, two methods of analysis were chosen. Firstly, a qualitative content analysis according to Mayring (2015), using audio recordings of the complete design prototyping processes with the special feature of including photographs of the process and the final prototypes. And secondly, an artefact analysis according to Lueger and Froschauer (2018) of the final individual and collaborative prototypes based on photographs. The two analytical approaches complement each other and were brought together in a method triangulation (Flick 2011). The qualitative content analysis sheds light on the production process and verbal descriptions of the producers. The artifact analysis goes beyond the linguistic dimension and opens up in particular the visual-haptic dimension of the prototypes for the evaluation.

Qualitative content analysis

In accordance with the standard procedure for qualitative content analysis (Mayring 2015), the following steps were carried out: first, determining the data sources by defining the material (see also ‘Research context and data selection’) and analysing its situation of origin as well as naming the formal characteristics of the material. Second, developing the question of analysis by defining the direction of analysis and an, in this case, explorative approach to theory development. Finally, the textual analysis and deductive category application (coding). The category development of potential design prototype qualities was based on previous research experience, multiple facilitations of design prototyping workshops, and research reflections in research diaries. This category development had two levels of abstraction. On a more concrete level: a material, visual-haptic, spatial, playful, and communicative quality. On a more abstract level: a transformative, process–object, and metaphorical

[2] Artefacts and prototypes are used synonymously, especially in the Methods section, as prototypes are the artefacts examined in the artefact analysis.

quality. In addition, a material visual language and a mediating role of the artefacts were considered as categories.

Due to the particularity of the close interweaving of the audio-recorded production process and the image data of the prototypes created, a specific methodological procedure was developed that included image data in the qualitative content analysis. This specific analysis scheme was composed of the following steps:

1. Determining coding categories derived from the potential qualities based on previous research experience.
2. Complete coding of the workshop transcripts, which included production process, discussions, and explanations of the producers. It turned out that the categories chosen were not suitable for coding the textual material and that the text alone was not sufficient for understanding the process. Based on these findings, it was decided to focus on specific units of analysis (description of the objects from the warm-up, and description of the individual and collaborative prototypes by the producers) and to include the image data in the content analysis.
3. Making visual collages from images of the final prototypes as background, and text descriptions of the prototypes by the producers as foreground (see Fig. 1). This allowed the images of the prototypes to be viewed and their descriptions to be understood simultaneously.
4. Changing the coding of the image-text collages from the potential qualities to a general category “relevant for further evaluation.”
5. Mounting all images of the final prototypes on one poster per workshop for a better overview for further evaluation (see Fig. 2 and 3).
6. Carrying out the artefact analysis (see below).
7. Focusing on three core aspects of design prototyping after conducting the artefact analysis: forms of collaborative prototyping, material metaphors, and material-metaphorical imagery. These categories were then used for the further content analysis.
8. Second round of coding with the new categories.
9. Answering of emerging questions from artefact analysis by consulting the material for the qualitative content analysis.
10. Comprehensive description of the results and three key aspects.

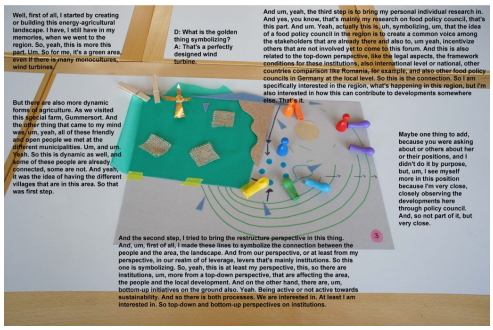

Fig. 1 Collage of an image of a prototype and the text of its description by the producer

Fig. 2 Poster with images of the individual and collaborative prototypes of the Romanian case study workshop as an overview for analysis

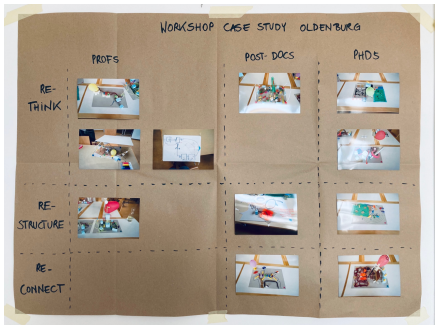

Fig. 3 Poster with images of the prototypes of the Oldenburg case study workshop arranged in a grid with columns for status groups and rows for working groups

Artifact analysis

For the detailed artefact analysis, a selection was made from the large number of artefacts produced in the project. The artefacts are prototypes that were produced individually and collaboratively within a design prototyping process. Artifacts from the selected workshops were analysed, thus covering both case studies. In the Romanian case study workshop, all individual prototypes (six) of one team (there were four teams in total) and all four collaborative prototypes were analysed (so then in total). In the workshop of the Lower Saxony case study, one individual prototype per status group (professors, post-doctoral researchers, PhD students) was analysed, each of which also represented a project realm (ReThink, ReConnect, ReStructure) (so three in total). The following data were available on the artefacts: photographs of all artefacts and the production process, audio recordings of the artefact production process, and audio recordings of the producers' description of the artefacts.

The procedure for the artefact analysis was carried out according to Lueger and Froschauer (2018), following the descriptive steps of research context, conditions of existence, descriptive analysis, everyday contextual sense, distanced-structural analysis, comparison, and summary. The analysis was carried out using photographs of the artefacts. To create an overall picture and for comparative analysis, all photographs were printed out and pasted on a large poster for each workshop. The arrangement of the photographs on the poster for the Romanian case study workshop was done according to the respective groups of the workshop and in such a way that the collaborative prototypes were arranged next to each other for comparison (see Fig. 2). The arrangement for the Oldenburg case study workshop was done in a grid, with the columns defined by the status groups and the rows defined by the working groups (see Fig. 3). For this specific analysis, the method was adapted especially in the area of descriptive analysis by making some additions to the catalogue of questions that serves as the basis for the description. The adaptations mainly covered the areas of materiality, structure of the elements, team processes, and metaphors (a detailed list of the specific questions can be found in the supplement).

Results

Forms of collaborative prototyping

Participants in the workshops used the design prototyping process to reflect on their own attitudes, communicate, and discuss ideas according to the task. The results of the analysis of the design prototyping processes show that the collaborative production of knowledge in prototyping takes place in very practical ways. Three different approaches can be distinguished in the creation of collaborative prototypes: *additive*, *integrative*, and *emergent* (see Fig. 4–6). *Additive* refers to participants leaving their individual prototypes largely unchanged in the collaborative prototyping phase, only pushing them together and possibly connecting individual aspects with a new object, e.g., a red thread. An *integrative* approach was identified when the participants exchanged, changed, and moved elements of the individual prototypes, i.e., actively worked on them together. *Emergent* refers to participants creating a completely new collaborative prototype based on the elements of the individual prototypes, but also adding new elements to it. Participants in a team who sit close to each other often proceed in a similar way in the production process—that is, they use similar materials or prototyping techniques, for example. The intensity of participants' communication through the artefacts varied greatly. There were participants who described the individual elements in great detail, while others saw their prototype as self-explanatory. For example, the position of individual elements was changed during the explanation of the artefacts by the producers. In addition, parts of the prototypes were deconstructed, rebuilt or added to during the collaborative prototyping phase. In both individual and collaborative prototyping, the role of metaphors is central. These emerged in the data in two forms: as material metaphors and as material metaphorical imagery to visually structure the ideas in the design prototypes.

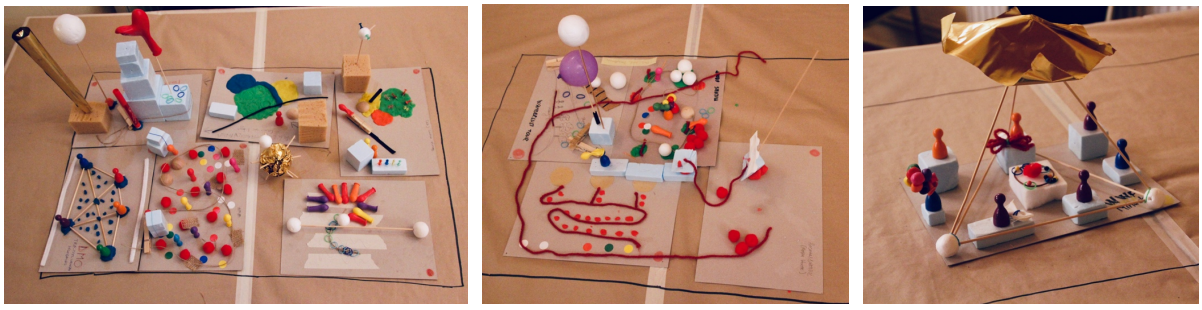

Fig. 4–6 Examples of the three identified forms of collaborative prototyping: additive (left), integrative (middle), and emergent (right)

Material Metaphor

When speaking of metaphors here, we are not referring to the linguistic figure of speech, but to the cognitive phenomenon that Lakoff and Johnson very vaguely described as “understanding and experiencing one kind of thing in terms of another” (1980, p. 5) and which forms the foundation of cognitive metaphor theory (CMT). Its main proposition is that metaphors play a central role in the way

people understand the world. Crucial to the analysis of metaphors in non-linguistic domains are three elements (Cila 2013; Forceville 2008): the source, which provides the original meaning of what is to be transferred; the target as the element to which the meaning is transferred; and the mapping, which describes the process of the transfer. The peculiarity of the metaphors that appear in design prototyping is that three-dimensional materials describe the source of the metaphors. This metaphor model is introduced based on the results of our research in this article and is called material metaphor. Table 2 summarises how the source and target of the material metaphor are defined and how the mapping is done.

Table 2 Description of the different elements of a material metaphor

Element	Definition
Source	Properties of a material or object are taken up and adapted in the context of the producer's idea in order to illustrate and explain it. The source medium is the material.
Target	A specific aspect of an idea that is to be represented and explained through the metaphor, and which manifests itself in the prototype. The medium of the target is actually the immaterial idea, but since it materialises in the design prototype, the medium of the target is also the material.
Mapping	Mapping of the material property to the aspect of the idea by the producer of the design prototype. Mapping takes place both conceptually-mentally and practically-physically when the corresponding material is used and adapted for the prototypical representation of the idea.

In this context, material refers to all two- and three-dimensional materials and objects, which can range from manufactured materials such as paper, fabric, rubber or plastic to natural materials such as leaves or stones. In this article, primarily materials are referred to that are suitable for design prototyping. In other words, materials that have a certain openness to interpretation, a low degree of predefinition, and a high degree of manipulability. A material metaphor is understood as the process of transferring the meaning of a material or object built from these materials to an idea that is represented with the material. The materials thus serve as inspiration for the metaphor, the representation of the idea, and its communication. Similar to Hekkert and Cila (2015), also in a material metaphor different categories can be distinguished, which serve as a source for the metaphor. Adapted to the medium of material, however, the categories are somewhat different: (1) the material itself (e.g., wood, plastic, modelling clay, etc.), (2) haptics (e.g., rough, soft, smooth, fluffy, etc.), (3) texture (e.g., permeable, porous, transparent), (4) shape (e.g., round, angular, etc.), (5) colour, and (6) other material properties (e.g., light, flexible, firm, pliable, etc.) (see Table 3).

Table 3 Examples of material metaphors sorted by the different source categories

Source category	Example metaphor
Material itself (e.g., wood, plastic, modelling clay, etc.)	• rubber = flexible • sponge = soaking up water to grow • hemp = natural, raw, sustainable • wood = standing for a specific wooden area, forest • plastic = artificial
Haptics (e.g., rough, soft, smooth, fluffy, etc.)	
Texture (e.g., permeable, porous, transparent)	
Shape (e.g., round, square, etc.)	• cube = institution • “I am angular because I think in straight lines and right angles” • ball = planet Earth
Colour	• green = nature • gold = wealth • red thread = guideline
Other material properties (e.g., light, flexible, strong, bendable, etc.)	• the properties themselves, but also the construction of the idea, e.g., for plasticine

The process of generating a material metaphor during design prototyping is not verbalised. It can only be observed that the workshop participants look at and touch the materials. For the recipients, material metaphors mix with what is visually represented by the prototype. The recipients also form their own metaphors with the material and representations. How many source categories of an object or material are metaphorically transferred often remains unclear. For example, the producer of a prototype used a green foil to symbolise nature with the colour green. In her explanations, however, it remained open whether aspects such as its transparency, size or the plastic material were also to be considered in the representation of her idea. This may suggest an absolute inaccuracy in the interpretation of design prototypes. On the other hand, it is precisely this openness to interpretation that also holds potential for connecting the prototypically represented ideas to the thinking of the recipients. Coupled with the possibility of looking at, touching and further constructing the design prototypes, the ideas can be grasped in many ways and developed further together. The following processes seem to take place when participants receive design prototypes (although the order may vary): (1) recipient sees the design prototype and interprets the visual representation; (2) recipient forms own material metaphors; (3) recipient hears the producer's metaphors, reflects on them, and mixes them with own metaphors; (4) recipient hears the producer's idea supported by the metaphors; and (5) recipient forms an interpretation of the prototype from this mixture. All participants of workshops are both producers and recipients of the design prototypes, depending on the phase and task of the workshop.

Material-metaphoric imagery

The second dimension in which metaphors come to light in design prototyping processes is in the different forms of representation and visual-haptic structuring of the ideas by the producers, which we call material-metaphoric imagery. Three different types can be identified (see Table 4 and Fig. 7–9). First, the *concrete-figurative* type, in which the representation of what is meant is direct, e.g., through the depiction of a landscape (river, road, meadows, fields, trees, etc.). Secondly, the *iconic* type, in which the visual-haptic representation of what is meant takes place via a pictorial metaphor, e.g., a light bulb stands for an idea. And thirdly, the *abstract-structural* type, where the visual-haptic elements tend to map or represent a certain structure, e.g., a cube stands for an institution, strings are the connections. The elements stand for something, but this is not necessarily obvious from the visual appearance—it requires concrete attribution by the producer. The different types of material-metaphorical imagery are not fixed entities but rather to be considered as being on a continuum from concrete to abstract. Moreover, elements of different types of material-metaphorical imagery are also mixed in a design prototype.

Table 4 Description of different types of material-metaphoric imagery and examples

Type	**Definition**	**Examples**
Concrete-figurative	Direct visual-haptic representation of what is meant	Trees, people, rivers, roads, sheep, meadows, etc.
Iconic	Visual-haptic representation of what is meant is done through a figurative metaphor	• circle = unity • house = institution • mirror = reflecting attitudes • loudspeaker = being an advocate for something • bridge = transition • magnifying glass = looking closely • jigsaw puzzle = being part of a whole • light bulb = idea • gate = goal • fish swarm pattern = swarm intelligence • wall = border, end • fire = burn for something
Abstract-structural	Visual-haptic elements depict a certain structure or represent something that the producer attributes to them, but which cannot be derived from the visual appearance	• individual building blocks/cubes represent institutions, sense units, organisations • strings represent connections

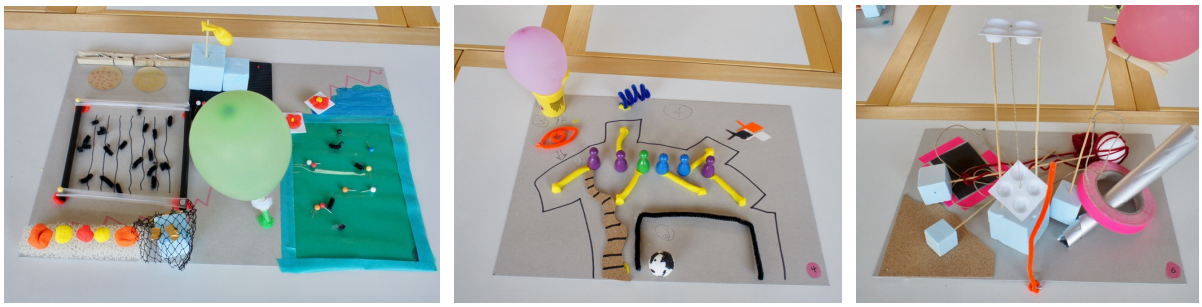

Fig. 7–9 Examples of the three identified forms of material-metaphoric imagery: concrete-figurative (left), iconic (middle), and abstract-structural (right)

Methodological findings

Besides the insights into the forms of collaborative knowledge production and the metaphorical quality of design prototyping, the data analysis also produced some methodological findings. These findings are based on the artefact analysis complemented by the content analysis used to understand the design prototyping process and to deepen the knowledge about the artefacts based on the descriptions provided by their producers. With regard to qualitative content analysis, it became apparent that the research question about qualities of design prototyping was too meta-level and that the initial qualities could not be operationalised in the form of coding categories. Therefore, it proved to be effective to consider in addition an artefact analysis. It also became apparent that a solely text-based content analysis is not sufficient for exploring the visual-haptic qualities of the specific material, and that the content can only be understood through the inclusion of image data or the detailed analysis of the artefacts.

After carrying out artefact analysis, it can be stated that the method is precise and that one dives deeply into the different levels, structure and three-dimensionality of artefacts. This results in special depths of knowledge, which on the one hand cannot be generated with other methods and on the other hand, however, refer mainly to the material-visual-haptic level. Emerging questions from the artefact analysis were answered by consulting the material from the qualitative content analysis. The artefact analysis according to Froschauer and Lueger is very schematic and general, and therefore requires individual adaptation of the questions to the analysed objects. However, it is also comprehensive, thorough, and precise. During the analysis phase, it is helpful to have a visual overview of the visual data and to have it present in the room. For the analysis of artefacts from photographs, a good shooting angle is important, and it is also helpful to have seen them in their original context. To what extent artefact analysis can answer a research question on its own cannot be answered from this research. Using it in combination with other methods of analysis seems to enhance the depth of knowledge and leads to mutual enrichment of the methods.

The researcher tried to put herself in a neutral observer's perspective during the data analysis. However, this was barely possible as she herself was part of the research team and moderated the workshops. To avoid a biased interpretation, it helped to discuss procedures, intermediate states of the analysis, and coding categories with research colleagues. In the course of the analysis, the role of

a potential addressee or attentive listener, who wants to know what knowledge and ideas are to be expressed by the prototypes, developed. To ensure the quality of the analysis, research colleagues were involved in the analysis as described above, adjustments were made to the artefact analysis to suit the research object, comparative analyses were carried out, and the analysis triangulation with qualitative content analysis including the image data was carried out. The combination of different research methods in a triangulation was important to the overall process, as the purely artefact-related analysis would be too arbitrary interpretatively. Therefore, the audio recordings of the producers' descriptions provided a good complement.

Discussion

Reflecting on the research design and methodological analysis

The analysis of design prototypes is the key method for understanding the design prototyping process in the context of knowledge co-production; therefore, artefact analysis was essential for understanding them and has been chosen as the core research method. It teaches us to look closely and allows us to explore the three-dimensional level that could not be captured otherwise. To ensure the quality of the analysis, adjustments were made to the artefact analysis to suit the research object and comparative analyses were carried out. Similar approaches to design prototyping can be found in connection with Design Thinking (Brown 2008) or other workshop methods, e.g., “Lego Serious Play” (Kristiansen and Rasmussen 2014). The kind of prototypes analysed in this research are highly individual, artificially produced only for the purposes of this project, and emerged from the individual workshop and team situations. The dataset is based on a research design that can be read as an exploratory approach to knowledge in design, but with a focus on supporting transdisciplinary research processes and collaborative knowledge production through design prototyping. The search for the appropriate methodological procedure to support the project and its transdisciplinary processes, as well as finding a suitable role for design in this process, took precedence over the pure evaluation of the visual-haptic, with its great potential to expand knowledge. With an exclusive focus on researching design or design prototyping, the research design would certainly have been structured differently. The focus would have been on capturing the design prototyping process (e.g., isolated from a transdisciplinary case study, with a focus on the observation of communication processes and adapted gathering of data). In relation to the research question about the qualities of design prototyping and their influence on collaborative knowledge production, it can be stated that not all of the qualities based on practical experience could be worked out on the basis of the empirical material. The qualities that were found mainly concern the form of representation of design prototyping; they provide fundamentally new insights into how knowledge can be expressed beyond language. The limits and choice of data, and method of analysis, resulted in a specific narrowing down to the metaphorical qualities of design prototyping. Additional research and further documentation and recording methods (video, etc.) are necessary for insights into the other qualities.

The following strengths of the chosen analysis methods and data selection were identified: audio recordings as the basis of the analysis were essential, but video recordings of the same quality would be even better. The photographs sufficiently depicted the 3D prototypes, and the montage on a common poster gave a good overview. The research notes and experiences through facilitation of the processes were essential for understanding the method and the process. The artefact analysis allowed for a deep description of the visual and they complemented each other well, with the qualitative content analysis of the process and the description of the artefacts by the makers. The triangulation of both methods of analysis using the photographs worked very well and led to a mutual enrichment of knowledge.

The following methodological limitations were identified: on the basis of the data material (artefacts and audio recordings of the process), few statements about the production process were possible, as certain internal processes (e.g., considerations about the choice of material or the production process, considerations about which aspects should be depicted, etc.) or non-linguistic communication between the participants (e.g., glances, gestures, etc.) could not be traced on the audio track. Supplementing this with specific video recordings (e.g., filmed from above for the building process and from the front for facial expressions, gestures, and interaction with the artefact) promises more in-depth insights here. However, since the projects were still in an early phase at the time of the workshops, where trust between the actors still had to be built up, the use of video recordings was deliberately avoided. The questionnaires (which were only used as a supplement) would have to be formulated more specifically to the method, the production process, and the qualities. Furthermore, the makers would have to be interviewed individually about their artefacts before and after the analysis. The role of the researcher as facilitator and analyst of the material could be considered too one-sided or biased. This could be overcome by having one person do the facilitation and another analyse the data. The research setting could be individually adapted to the qualities to be studied, e.g., focusing on material metaphors.

Reflecting on the artefacts

The design prototypes that are created in the process of design prototyping and serve as the basis for the artefact analysis are of a special nature for various reasons. For example, they are very short-lived, as they only exist within the workshop and for the purpose of the workshop. Whether reference is made to the prototypes again at a later point in time depends on the course of the project. It is rather the insights and ideas that result from the work with the prototypes that outlast the period of use. Their production is predetermined by the workshop structure and relatively strictly regulated in terms of time.

Furthermore, the attribution of meaning and the reflection of design prototypes is special. The attribution of meaning takes place through their materiality and by producers and recipients. Attributions are very individual and cannot be assigned to specific groups of actors. Criteria for different attributions of meaning can be: family, cultural or social attribution of meaning to certain materials (e.g., valuable, worthless, environmentally friendly, environmentally harmful, playful, serious, natural, artificial, funny, strong, weak, colour meanings, shape meanings, structure [absorbent,

permeable, malleable, transparent], etc.). Reception of the artefacts is unusual as their original meaning is hardly understood by outsiders without a corresponding explanation by the producers. Outsiders would rather perceive them as art objects and an obvious function is not recognisable. Therefore, reception of the artefacts in the original sense is limited to the group of workshop participants and is only available via photography to a relatively small circle. A comparative examination of the artefacts showed that the common features of the artefacts of each workshop were the same task, source material, and structure of the workshop. The individual differences resulted from the workshop's aim, the producers, their institutions and ideas, and the production processes. The criteria examined for similarity were: characteristics of individual elements and their arrangement on the cardboard platforms; materials and techniques used; spatial structures; colourfulness; and metaphors and symbolism. Differences that can be attributed to the different status groups or working groups could not be identified.

Reflecting on material metaphors

The open formulation of metaphor by Lakoff and Johnson (1980) has led to it being taken up many times by other disciplines and applied to fields outside language. Charles Forceville (2008), for instance, dealt with metaphor in comics and advertising graphics and coined the term multimodal metaphor for "metaphors in which target, source, and/or mappable features are represented or suggested by at least two different sign systems (one of which may be language) or modes of perception" (Forceville 2008, p. 463). By modes, Forceville means the following: (1) pictorial signs; (2) written signs; (3) spoken signs; (4) gestures; (5) sounds; (6) music; (7) smells; (8) tastes; and (9) touch (Forceville 2009, p. 23). Accordingly, he defined monomodal metaphors as metaphors whose target and source are exclusively or predominantly rendered in one mode. In contrast to monomodal metaphors, multimodal metaphors are metaphors whose target and source are each represented exclusively or predominantly by different modes. This mapping then leads to a transformation of that target. With his introduction of multimodaltity of metaphors, Forceville paved the way for material metaphors as they are also multimodal.

In their work, Hekkert and Cila (2015) were the first to describe the application of metaphors in the field of design and for 3D objects; therefore they coined the term product metaphor. They defined product metaphor "as any kind of product whose design intentionally references the physical properties (e.g., form, sound, movement, smell, and so on) of another entity for specific, expressive purposes" (Hekkert and Cila 2015, p.199). To create a product metaphor, a designer merges the target with the source by projecting certain physical, functional or operational properties of the source onto compatible properties of the target (e.g., form, colour, material, texture, movement, animation, use, sound, smell) (Cila 2013). To analyse which properties can be physically transferred to the target medium, Hekkert and Cila used eight categories: form (i.e., shape, outline, colour), interaction, sounds, movement, material/texture, smell/taste, name, and graphics (2015, p. 206–208). In contrast to the metaphors emerging in design prototyping, Hekkert and Cila are concerned with metaphors of industrially produced end products, where the product is the target of the metaphor. With their

categories of analysis, they have for the first time presented a scheme through which three-dimensional objects and their metaphorical content can be described. Nevertheless, in the literature there was a lack of a metaphor model that could be used to describe three-dimensional materials as the starting point (source) of metaphors. This gap was filled with the introduction of the material metaphor.

Design prototyping as collaborative knowledge production

In order to illuminate the results of the empirical data analysis on different forms of collaborative knowledge production and the metaphorical quality of design prototyping in a larger theoretical context, they are discussed using the principles introduced by Norström et al. (2020).

Table 5 Addressing principles of collaborative knowledge production through design prototyping

Principles of Norström et al. (2020)	**Addressing through design prototyping**
"Context-based: situate the process in a particular context, place, or issue"	Design prototyping can always be carried out individually and in a context-based manner due to its embeddedness in workshop formats and the flexibility of the specific prototyping task. The individual artefacts are answers to specific questions and thus also context-based. Elaborating the metaphorical qualities of design prototyping, context-specific and individual aspects of the artefacts are raised to a more general level, in which differences beyond the individual become visible and discussable, and comparative considerations are possible. Metaphors and figurative elements are strategies to make individual experiences more accessible to recipients. Therefore, design prototyping is a method of expressing context-based experiences and knowledge.
"Pluralistic: explicitly recognise the multiple ways of knowing and doing"	Design prototyping is structured to allow as many voices as possible to be heard, and to encourage different ways of knowing (e.g., knowledge that cannot be well verbalised) and of expression (visual-haptic). Material metaphors and visual-haptic imagery serve as access points to multiple ways of thinking and acting.
"Goal-oriented: articulate clearly defined, shared and meaningful goals that are related to the challenge at hand"	Common goals can be developed through design prototyping. A reference back to these goals manifested in the artefacts is also possible at a later stage of the project. The prototypes can also be used to share the developed goals with other actors and thus, for example, disseminate them to society.
"Interactive: allow for ongoing learning among actors, active engagement, and frequent interactions"	Design prototyping promotes the active involvement of different actors in a specific concern. The later reference back to the created artefacts enables an ongoing learning process. The artefacts can also be used to further develop them iteratively. The metaphorical qualities of design prototyping contribute to active participation and strengthen interactive collaboration between actors.

Collaborative knowledge production primarily describes the basic attitude that it is important to involve diverse actors in research and knowledge production processes. This approach is therefore placed more on the level of knowing-that than knowing-how. The principles proposed by Norström et al. (2020) also tend to name conditions. While design prototyping and its metaphorical qualities support these conditions, it is also effective in the area of knowing-how, i.e., in research practice, in that it shows ways in which collaborative knowledge production can take place in a very practical way and connects the entities of collaborative knowledge production in the sense of integration.

Conclusion

The discussion of the research results and analysis methods has already shown that further research is needed for an even deeper understanding of design prototyping processes. For example, research settings could be more purposefully tailored to explore further qualities of design prototyping, and to add to existing findings. There is also a need for more research into the use of artefact analysis to unlock the potential of design prototypes, especially in combination with video analysis. This will serve to expand the repertoire of analytical methods for unlocking visual-haptic data. Furthermore, the linkage of the findings on material metaphors to Schön's (1979) concept of generative metaphor for reframing the problem setting in transdisciplinary processes could be examined. Opening up the theoretical discourses on boundary objects and epistemic objects (Dickel 2019; Ewenstein and Whyte 2009; Leigh Star and Griesemer 1989) for the use of design prototyping could also be valuable. The connections between the visual-haptic knowledge processes of collaborative knowledge production and concepts of different forms of knowledge (target, systems, transfomative knowledge) (Pohl and Hirsch Hadorn 2007), and especially tacit knowledge (Polanyi 1966), are still little researched. In particular, the question of the extent to which material metaphors can represent a bridge for cognition in this process is of interest. And it is still unclear how the exact encoding and decoding of material metaphors is done by producers and recipients. As mentioned in the discussion, working with design prototypes is highly individual and context-based. However, the findings on material metaphors and the material-metaphorical imagery in turn open up a more general perspective of looking at individual results, which also allows for comparative perspectives.

The application of design prototyping in the context of collaborative knowledge production is already largely detached from the design context. Although the method of design prototyping originates from design, it is very different from the usual application of prototyping there (Author and V. 2021). Nevertheless, the results of this research have an influence on design and design research on various levels. On the one hand, knowledge of the qualities of designs and their influence on collaborative knowledge production in general, and on insights into material metaphors and material-metaphorical imagery in particular, can make the selection of design-based methods more purposeful. On the other hand, it opens doors for the application of further creative and visual-haptic methods and raises their status. Furthermore, the findings contribute to the discourse on design-based knowledge production and expand the functional use of design and design-based methods in the context of transdisciplinary sustainability research and collaborative knowledge production. The analysis of design prototyping and findings on its metaphorical quality reflect how knowledge can be expressed individually and collaboratively in a visual-haptic way. As a complement to the linguistic-textual dominance in the communication and production of knowledge, the results are of great importance for epistemology, the philosophy of science, and the practice of collaborative knowledge production in research processes—and are thus relevant far beyond the design context.

Using design prototyping for collaborative knowledge production, can be effective on different levels. The presented research emphasises the importance of the visual-haptic in knowledge production and

for the communication of knowledge. It provides in-depth insights into different forms of collaborative knowledge production (additive, integrative, and emergent) and the role that material metaphors and forms of material-metaphorical imagery can play in this process. Material metaphors translate and transport knowledge and offer a connection to the knowledge of others. They can be seen as bridges that allow access to other levels of thinking because they appeal to many senses. When working with design prototypes, complex issues have to be broken down, represented with the help of material and thus simplified and translated. This translation into the material breaks down disciplinary thinking and language, as the visual-haptic is also a form of expression in its own right, but one that transcends disciplines. The findings on the forms of material-metaphorical imagery provide insights into the visual structuring of human thought processes and facilitate mutual understanding of how people sort their own thoughts and render them linguistically and textually. If material metaphors and visual imagery can be interpreted as epistemological and communicative strategies of collaborative knowledge production, this also has insight potential for cognitive processes in general and the application of further visual-haptic methods in such processes. The material thus not only brings out epistemic aspects, but also unfolds a transformative potential, as processes of change can be initiated and promoted through shared understanding and knowledge production. Design prototyping and its metaphorical quality promises to be a bridge that can link the research practical with the theoretical, the individual with the general, and the known with the unknown—not only in workshops but also for further research into the role of design in collaborative knowledge production.

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Supplementary material

Adapted questions for the descriptive analysis of the concrete case (based on Froschauer and Lueger):

- Materiality
    - What elements do the prototypes consist of?
    - Which individual materials were used?
    - Do sensory properties play a role? (smell, haptics, acoustics, appearance; special features of the surface such as strength, colour, consistency)
    - How were the materials used (manipulated, deformed, destroyed, etc.)?
    - Which colours, materials dominate?
    - Are there material properties that are particularly significant for the artefact? Why? Do these have a function?
- Structure
    - What components does the artefact consist of? (connections and boundaries; criteria of difference between different components; ambiguities or contradictions; significance of the components for the artefact)
    - How can the individual elements be characterised? (characterisation and functions of the parts; differences and similarities)
    - What is the relationship between the different elements? (main and secondary elements; foreground and background; centre and periphery; social, functional, temporal or aesthetic relationships)
    - What is the significance of striking discrepancies between individual components? (e.g. for the contexts of use, the actors involved, the appearance of the artefact)
    - How were the elements arranged?
    - How was the platform used (distribution, rather foundation or canvas)?
    - How were two- and three-dimensionality combined?
- Overarching questions related to specific groups or the whole team
    - Do participants sitting together proceed in a similar way?
    - Are there recurring elements in the group?
    - Are the collaborative prototypes emergent, integrative or additive prototypes?

Questions for the description by the producers:

- Materiality
    - Do materiality, colours and shapes play a role in each element? Do they have meaning every time?
- Metaphor
    - What material metaphors have been used?

12.Grants and Funding

I was very lucky to benefit from the research grant awarded to the Leverage Points project through the Volkswagen Foundation and the Niedersächsisches Ministerium für Wissenschaft und Kultur (Grant number A112269), Leuphana University's fund for young researchers to participate in multiple conferences, and a 'ProScience' scholarship for female researchers also by Leuphana University of Lüneburg. I am very thankful for this support.

13. Author's Contributions

The following table and the other listings in this chapter contain all information on the articles of this dissertation in accordance with §12 and §16 of the guideline for cumulative dissertations in sustainability science at Leuphana University of Lüneburg (version of January 2012).

I hereby declare that the information contained in this chapter is individually and collectively true and correct.

Bamberg, D. Perkert

Table 3: Overview of the author's contributions to this dissertation

Art. No.	Title	Authors with their specific contributions*	Daniela Peukert's contribution	Weighting factor	Medium – Quality	Status	Conference contributions
1	'Entwurfsbasierte Interventionen in der transdisziplinären Forschung'	Daniela Peukert: a–f Ulli Vilsmaier: a, f	Co-author with predominant contribution	1,0	Book Springer *Interventionsforschung* Peer review Citations: 2; Downloads: 1,800	Published in 2019 https://doi.org/10.1007/978-3-658-22048-8_10	DRS 2016 DGS 2026 DGTF 2016 ITD 2017
2	'Designing a transformative epistemology of the problematic: A perspective for transdisciplinary sustainability research'	Esther Meyer: a–f Daniela Peukert: a–f	Co-author with equal contribution	1,0	*Social Epistemology* Double-blind peer review Citations: 1; Downloads: 325 Impact Factor 2020: 1.603	Published in 2020 https://doi.org/10.1080/02691728.2019.1706119	LP 2019 ITD 2019
3	'Facilitating collaborative processes in transdisciplinary research using design prototyping'	Daniela Peukert: a–f David P.M. Lam: a, c, f Andra I. Horcea-Milcu: a, c, f Daniel J. Lang: a, c, f	Co-author with predominant contribution	1,0	*Journal of Design Research* Double-blind peer review CiteScore 2020: 0.8	Published in 2021 https://doi.org/10.1504/JDR.2020.118673	Transformations 2017 PECS 2017 LP 2019 Susplace 2019 IDR 2019 EASST 2020
4	'Collaborative design prototyping in transdisciplinary research: An approach to heterogeneity and unknowns'	Daniela Peukert: a–f Ulli Vilsmaier: a, f	Co-author with predominant contribution	1,0	*Futures* Double-blind peer review Impact Factor 2020: 3.073	Published in 2021 https://doi.org/10.1016/j.futures.2021.102808	Transformations 2021 DGS 2021 ITD 2021
5	'Design-based approaches to collaborative knowledge production in transdisciplinary research'	Daniela Peukert: a–f	Single author	1,0	*Not defined*	In preparation for re-submission	DRS 2022
			Sum	**5,0**			

* (a) = Conception of research approach
(b) = Development of research methods
(c) = Data collection and data preparation
(d) = Execution of research
(e) = Analysis/Interpretation of data or preliminary results
(f) = Writing or substantive rewriting of the manuscript

Conference contributions (acronym, title, society, date, place, website)

DRS 2016	Design Research Society Conference 2016, 27–30 June 2016 in Brighton, UK, website: https://www.drs2016.org/
DGS 2026	Deutsche Gesellschaft für Soziologie, 38. Kongress 2016, organised by University of Bamberg, 26–30 September 2017 in Bamberg, Germany, website: https://kongress2016.soziologie.de
DGTF 2016	Deutsche Gesellschaft für Designtheorie und -forschung, Jahrestagung 2016, organised by Hochschule Anhalt, 18–19 November 2016 in Dessau, Germany, website: http://www.dgtf.de/tagungen/tagung2016
Transformations 2017	Transformations 2017: Transformations in Practice, organised by University of Dundee, 30 August – 1 September 2017 in Dundee, Scotland, website: http://www.transformations2017.org/
ITD 2017	International Transdisciplinarity Conference 2017, organised by Leuphana University of Lüneburg, 11–15 September 2017 in Lüneburg, Germany, website: https://transdisciplinarity.ch/de/veranstaltungen/itd-conferences/itd-ch-17/
PECS 2017	Conference of Programme on Ecosystem Change and Society 2017, 07–10 November 2017 in Oaxaca, Mexico, website: https://pecs-science.org/
LP 2019	Leverage Points for Sustainability Transformations Conference 2019, organised by Leuphana University of Lüneburg, 6–8 February 2019 in Lüneburg, Germany, website: http://leveragepoints2019.leuphana.de/
Susplace 2019	Sustainable Place Shaping Final Conference 2019, 07–10 May 2019 in Tampere, Finland, website: https://www.sustainableplaceshaping.net/home/final-event/
ITD 2019	International Transdisciplinarity Conference 2019, organised by University of Gothenburg, 10–13 September 2019 in Gothenburg, Sweden, website: https://transdisciplinarity.ch/de/veranstaltungen/itd-conferences/itd-ch-19/
IDR 2019	Interdisciplinarity Revisited Symposium 2019, organised by the Volkswagen Foundation, 3–4 October 2019 in Berlin, Germany, website: https://www.volkswagenstiftung.de/interdisciplinarity-revisited
EASST 2020	European Association for the Study of Science and Technology Conference 2020, 18–21 August 2020 in Prague, Czechia/online, website: https://easst.net/easst-4s-2020/

Transformations 2021	Transformations 2021, 17–18 June 2021 online, website: https://www.transformationscommunity.org/conference-2021
DGS 2021	Frühjahrstagung Deutsche Gesellschaft für Soziologie 2021, Sektionen 'Methoden der empirischen Sozialforschung' und 'Umweltsoziologie', organised by Forschungszentrum Jülich, 18–19 June 2021 in Jülich, Germany/online, website: https://fz-juelich.de/conferences/fruehjahrstagung-dgs/DE/Home/home_node.html
ITD 2021	International Transdisciplinarity Conference 2021, 13–17 September 2021 online, website: https://akademien-schweiz.ch/de/current/events/itd-conference-2021
DRS 2022	Design Research Society Conference 2022, 25 June –03 July 2022 in Bilbao, Spain/online, website: https://www.drs2022.org/

14. Author's Declaration

Daniela Peukert
Alte Seilerei 22
96052 Bamberg
E-mail: daniela.peukert@leuphana.de | daniela.peukert@gmx.de

I hereby declare that I have neither undertaken nor applied to undertake any other doctoral assessment.

I further affirm that the dissertation with the title '*Design methods for collaborative knowledge production in inter- and transdisciplinary research*' has not been submitted to any representative of any faculty, that I am submitting the dissertation only in this and no other doctoral procedure, and that I have not previously failed any other doctoral assessments.

I furthermore declare that I composed the submitted dissertation '*Design methods for collaborative knowledge production in inter- and transdisciplinary research*' independently and without having recourse to prohibited means. I have not used any aids or texts other than those I have indicated. All passages taken in verbatim or substance from other works have been identified.

Bamberg, D. Peukert