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Material metaphors: An approach to collaborative knowledge production in transdisciplinary sustainability research

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Abstract: 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 in inter- and transdisciplinary processes in sustainability research. Nevertheless, collaborative knowledge production 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-haptic dimension, which allows access to other levels of thinking as it appeals to many senses. Therefore, this paper shows the application of design prototyping, as one specific design method, for collaborative knowledge production and integration in inter- and transdisciplinary research processes. The findings cover three different approaches to collaborative knowledge production and shed light on the role of material metaphors as translator of different cognitive modes and bridge to the knowledge of others.

Keywords: design methods; prototyping; material metaphor; transdisciplinarity

1. 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 multilayered 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 (Peukert 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

Nevertheless, 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 (Peukert and Vilsmaier 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 (Peukert 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.

2. Method of analysing design prototyping

2.1 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 Peukert 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
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 (Peukert et al. 2021). The processes were recorded by taking pictures, audio recordings, 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 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. 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 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.

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

<table>
<thead>
<tr>
<th>Workshops</th>
<th>A: LP Team Workshop, Lüneburg</th>
<th>B: LP Case Study Transylvania, Romania, NGO Workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaborative research activity</td>
<td>Interdisciplinary team building</td>
<td>Transdisciplinary visioning</td>
</tr>
<tr>
<td>Guiding question</td>
<td>How to bring together local needs, own, and group research? How to get to know each other and their research interests?</td>
<td>How to bring together the work from different initiatives and make them visible?</td>
</tr>
<tr>
<td>What was built during design prototyping?</td>
<td>In four individual steps: the case study area, the research project, the personal research, and potential connections</td>
<td>In step one individually: contribution of organisation to the shared vision; in step two collaboratively: common pathway to the shared vision</td>
</tr>
</tbody>
</table>
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 |

2.2 Analysis

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.

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
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

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Figure 1. Collage of an image of a prototype and the text of its description by the producer
For the detailed artefact analysis, a selection was made from the large number of artefacts produced in the project. 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.

3. Results

3.1 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. 4a–c). 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 (e.g. next to each other or at the same table) 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.

Figure 4a–c. Examples of the three identified forms of collaborative prototyping: additive (left), integrative (middle), and emergent (right)
3.2 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>
<thead>
<tr>
<th>Element</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>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.</td>
</tr>
<tr>
<td>Target</td>
<td>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.</td>
</tr>
<tr>
<td>Mapping</td>
<td>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.</td>
</tr>
</tbody>
</table>

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.).

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.

3.3 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 Fig. 5a–c). 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.
4. Discussion

4.1 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 the methodological procedure in Design Thinking processes (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
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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. Furthermore, the producers 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.

4.2 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. Categories of similarity that emerged during the comparative examination were: structure 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.

4.3 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 multimodality 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.

5. 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, transformative 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 (Peukert and Vilsmaier 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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6. References


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**Daniela Peukert** is a design researcher at the Faculty of Sustainability Science, Leuphana University of Lüneburg, Germany. In her research she explores the epistemic qualities of design prototyping and its potential to foster integration within transdisciplinary research processes and knowledge co-production for sustainability transformation.