Designing Transdisciplinary Sustainability Science

A Comparative Analysis of a Transdisciplinary Research Framework and Design Thinking

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LUCSUS
Lund University Centre for Sustainability Studies

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Abstract:

Sustainability science has to solve some of the most complex problems of our times. So far, the field of sustainability science is more known for its promises than its solutions. It is successful at creating knowledge but is lacking in terms of developing actionable knowledge. The transdisciplinary process incorporates practitioners and the people for whom the solution is intended in the research process. This cooperative approach aims at creating solutions for science and practitioners within the same research process. As such, transdisciplinary research is the most promising approach in sustainability science to solve sustainability problems; however, its difficult execution is hindering its potential success. Solutions for sustainability problems are urgently needed, so the advancement of sustainability frameworks and approaches is necessary and relevant.

The aim of my research is to find out how and to which extent the design thinking can support the advancement of the transdisciplinary framework by Lang et al. (2012) as it described the 'ideal' transdisciplinary research process. My approach is to compare the framework with design thinking and analyze the differences to find points of improvement for transdisciplinary framework in sustainability science. Using a qualitative comparative approach, I compare every single step of both frameworks to define and analyze their differences.

The overall result of my research is that I found several potential ways to advance the transdisciplinary framework by Lang et al. (2012). The inclusion of certain parts of design thinking can increase the quality of the outcomes for the people the 'product' is intended for. Furthermore, my analysis shows that problem understanding and solution development can be advanced. Another finding is the opportunity to improve the guidelines of iteration of the transdisciplinary framework. This concerns the iteration of steps within the process and the entire process. Iterations have far reaching benefits, such as developing prototypes and additional feedback before the implementation of the final product. Therefore, I argue for a better integration of iterative guidelines in the transdisciplinary framework.

However, the advancements may compromise the applicability of the transdisciplinary framework towards actual research. The broad variety of sustainability problems prevented me from defining specific criteria for its range of application. Therefore, I could only answer how the design process can advance the transdisciplinary framework, but I could not fully answer to which extent. My thesis establishes a first connection between design thinking and transdisciplinary sustainability science by showing possible improvements for the framework by Lang et al. (2012. Further research regarding the limitations and applicability in actual research processes are necessary to validate my findings

Keywords: 6 words: Design Thinking, Sustainability Science, Research Process, Interdisciplinarity, Problem Solving, Comparative Analysis

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1 Introduction

1.1 Overview

“There is arguably no example in the history of science of a field that from its beginnings could span such distinct dimensions and achieve at once ambitious and urgent goals of transdisciplinary scientific rigor and tangible socioeconomic impact“ (Bettencourt & Kaur, 2011, p. 19540). Sustainability science (SS) is still a relatively young and developing field of research which aims at solving some of the most complex contemporary and future challenges. So far, SS has been more successful in defining problems than developing solutions for them (Miller, 2013). Transdisciplinary research is the most promising approach in SS to solve sustainability problems; however, its difficult execution is hindering its potential success. The transdisciplinary research process incorporates practitioners and the people for whom the solution is intended in the research process. Perhaps, SS should not only include non-academics in their research but look beyond the borders of academia for novel approaches to finding solutions as well:

> “The upcoming generations of college graduates will be inheriting the most problematic world of opportunities and challenges that has ever existed. This ever-increasingly complex, interconnected, and interdependent world must evolve into a [sic] innovative, creativity- driven culture to tackle the wicked problems that conventional approaches often fail at”. (Rittel and Weber, 1973 in Horst & Melvin, 1973).

In my thesis, this unconventional approach is Design Thinking (DT). Design thinking is already used in many disciplines with great success when breakthrough ideas are needed (Camacho, 2016). Therefore, I will research if the process used in DT contains aspects that could be useful for the advancement of transdisciplinary research in SS. Advancing the field of SS is necessary as it is currently “more marked by its promises than its achievements” (Thorén, 2015, p. 12). My research focuses on the advancement of a specific framework which describes the ‘ideal’ transdisciplinary research process. These include new ways to integrate users in research and more clarity on the integration of iteration within the framework. While potentially advancing the framework, it may be hampered by limitations regarding its applicability.

The first chapter serves as an overview and provides the reader with a positioning of my thesis in the academic context of SS. I also introduce the concept of DT and its connection to transdisciplinary research in SS and present my research aim and question. The second chapter is about the qualitative methodology and concept I use in this research. Chapter three is where I introduce and compare the individual steps of the transdisciplinary research process and design process. The steps are systematically analyzed in chapter four and the results presented in chapter five. In chapter six, I discuss the implication of the results for my research question and their limitations. I also discuss the application of my findings in other contexts and suggest further research to expand my findings. I conclude my research in chapter seven.

1.2 Positioning within Sustainability Science

The problems SS deals with in human-natural systems are characterized by high degrees of complexity, urgency, lack of clear solution, and are of societal rather than scientific origin (Wiek, Withycombe, & Redman, 2011). Some sustainability problems feature high levels of complex interdependencies, lack a problem definition and have contested social values which make them wicked problems (Jerneck et al., 2011; Horst & Melvin, 1973). To solve sustainability problems, two branches have developed within SS: descriptive-analytical and transformational research (Wiek & Lang, 2016). Descriptive-analytical SS research focuses on sustainability problems by describing and analyzing the complexity, dynamics, and cause-effect relations of their individual aspects (Wiek & Lang, 2016). Transformational SS research aims at developing evidence-supported solution options for sustainability problems; solution options are actionable knowledge which, if applied, can create real-world sustainability changes (Wiek & Lang, 2016). This stream of research often includes non-academic actors (Wiek & Lang, 2016). Although the streams are described as separate, they are connected since problem of this sort often need to be described before a transition solution can be found (Wiek & Lang, 2016).

In its short existence, the descriptive-analytical stream of SS research has produced knowledge relevant to our understanding of the complex problems of human-natural systems (Miller, 2013; Miller et al., 2014). However, sustainability scientists of the transformational stream struggle to translate their scientific knowledge into actionable outcomes for society (Miller, 2013). To find ways of improving the transformational stream of SS, more solution-oriented research is needed (Wiek & Lang, 2016). One way to overcome this problem could be to include more non-academic actors into SS research (Miller et al., 2014). Again, the inclusion of external actors in the research process seems to be the most promising solution as the increased ownership of the solution by other actors leads to more willingness to change of these actors (Miller, 2013).

The only approach towards solving sustainability problems in SS which combines descriptive-analytical and transformational research, and integrates academic and non-academic actors is transdisciplinary research. This approach focuses on the integration of knowledge from different scientific disciplines and societal actors throughout the entire process (Thorén, 2015). Transdisciplinary mediated solutions incorporate transformative ‘real-world’ solutions for the practitioners of the process and scientific knowledge creation for the scientists in a mutual learning process (Lang et al., 2012). Although the notion of SS becoming transdisciplinary at some point has “almost universal agreement” (Thorén, 2015, p. 17) among sustainability scientists, successful employment of it is difficult. One problem of transdisciplinarity is the level of integration of practitioners by scientists (McGreavy, Hutchins, Smith, Lindenfeld, & Silka, 2013). This can lead to problems regarding the power relations or hierarchy of the research team (Felt, Igelsböck, Schikowitz, & Völker, 2016). Further problems in the transdisciplinary process include discontinued participation, communication issues, limited solution options, and the vagueness of results (Lang et al., 2012). Finding solutions to these problems and advancing the capacities of transdisciplinary research to successfully approach complex problems is, according to McGreavy et al. (2013), one key contribution of institutions of higher education. Based on a review of peer-reviewed articles, Brandt et al. (2013) claims that the field of transdisciplinarity still has many chances to develop.

Brandt et al. (2013) identified two groups of peer-reviewed papers: "1) research focusing on the development of theoretical transdisciplinarity frameworks and 2) solution-orientated research that seeks to apply transdisciplinarity to real-world projects" (p. 5). In my research, I focus on the first group of research papers by aiming at an advancement thereof. The advancement of theoretical frameworks in transdisciplinary science is important to improve the communication and application of the concept by practitioners and researchers in actual transdisciplinary research (Brandt et al., 2013)

To represent theoretical frameworks in transdisciplinary sustainability science, I chose the framework developed by Lang et al (2012). The framework works as a template for how transdisciplinary research is to be carried out in an ideal way and is largely based on a framework developed by Jahn (2008). What Jahn (2008) present in their paper is an extensive literature based analysis of what could "be considered the main features of an emerging shared framework of transdisciplinarity" (p. 1) and their paper provides a foundation for how to carry out 'best practice' transdisciplinary research processes. Lang et al. (2012) adapted this model slightly to provide a stronger focus on SS and this emphasis on SS was the reason why I chose to use the paper by Lang et al. (2012) as my object of study. From here on, I will refer to the Lang et al. (2012) approach interchangeably as a 'template', 'model' or 'framework'.

This model has gained recognition amongst both scholars and practitioners and is applied in multiple theoretical and practical contexts. It is used in academic teaching at LUCSUS at Lund University Sweden, and at Leuphana University Lüneburg, Germany (Jahn, Bergmann, & Keil, 2012), as well as in actual research projects (Jahn et al., 2012). Also, Brandt et al. (2013), in their review of transdisciplinary research in SS, uses the framework by Lang et al. (2012) as a rough outline for the phases it goes through, pointing to a general applicability and attractiveness of the template for illuminating steps of transdisciplinary research. Theorists of transdisciplinarity generally agree that the ideal process phases of a transdisciplinary framework follow the templates put forward by Lang et al. (2012) and Jahn et al.

(2012) (McGreavy et al., 2013). The focus of the framework also lies on its applicability for actual research practice (Lang et al., 2012; Jahn et al. 2012). The framework by Lang et al. (2012) is similar to several other frameworks within the same area of science, which raises its representative value for theoretical transdisciplinary research in SS (Lang et al., 2012). To this point, the article by Lang et al. (2012) has been downloaded over 7200 times and cited 264 times with a growing trend between 2012 and 2017 (SpringerLink). The articles referring to the framework by Lang et al. (2012) are mostly published in the journals *Sustainability Science, Sustainability, and Current Opinion in Environmental Sustainability* (SpringerLink). With this as a back drop, I find it justified to use the Lang et al. (2012) paper for my research into the improvement of an ideal template for transdisciplinary sustainability processes, based on its broad application possibilities and recognition within the field it has received.

Even though the paper by Lang et al. (2012) and its predecessor by Jahn et al. (2012) have been exemplified as representative of transdisciplinary research process models, it has not reached an agreed upon status as the standard approach. Transdisciplinarity scholars agree that there is the need for a coherent research framework for transdisciplinary research, but there seems to be lacking consensus and clear direction to what should be classified as the best template (Brandt et al., 2013). The transdisciplinary research field is a very broad and diverse area of research and is in constant flux and development, making it difficult to conclude on set procedures. Research methods used are numerous and a specific toolbox has so far not been established (Brandt et al., 2013). The research framework by Lang et al. (2012) only highlights a rough guideline of how transdisciplinary research may look, but as stated in the previous section, the papers by Jahn et al. (2012) and Lang et al. (2012) have been recognized as the most representative. Therefore, even though there are some limitations to the generalizability of their template, it serves as a valid example of an 'ideal' transdisciplinary research framework for my research.

Another limitation of my research is the theoretical focus and lack of transferability to "solution-orientated research" (Brandt et al., 2013, p. 5) which is deemed as the second important ambition of transdisciplinary research. My timeframe and scope did not allow for an inclusive look at the practical furthering of transdisciplinary processes; however, I view the theoretical templates underpinning a move towards better solutions and application of "transdisciplinarity to real-world projects" (Brandt et al., 2013, p. 5). I am focusing on improving the particular research framework of Lang et al. (2012), acknowledging that the "impact this [transdisciplinary] research is having on the wider academic community" (Brandt p.2) is unknown. This lack of information is partly due the fact that it is "unclear how much transdisciplinary sustainability science is being undertaken" (Brandt et al., 2013, p. 5) as it is not fully represented in peer-reviewed journals. The framework by Lang et al. (2012) serves as an initial entry point for DT into transdisciplinary research to first find differences and then potential improvements.

1.3 Introduction to Design Thinking

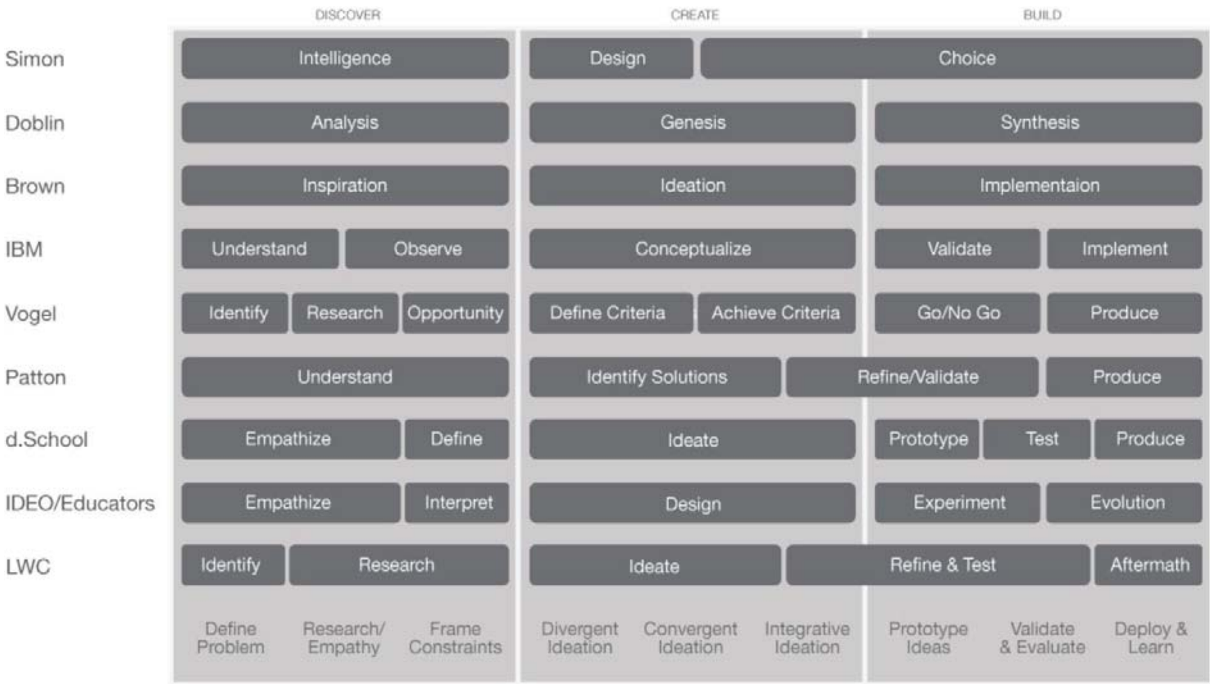
The selection of DT for the possible improvement of transdisciplinary research in SS is based on several criteria. Firstly, DT fulfils the same key arguments that Lang et al. (2012) used to highlight the importance of transdisciplinary research as a new type of research collaboration. These arguments include that every relevant stakeholder related to the problem is incorporated to ensure "the constructive input from various communities of knowledge" (Lang et al., 2012, p. 26). Furthermore, "research on solution options requires knowledge production beyond problem analysis, as goals, norms, and visions need to provide guidance for transition and intervention strategies" (Lang et al., 2012, p. 26). The second reason for the selection of DT is that the problems it tries to solve are also based on societal issues and are defined by complexity and wickedness. The notion of the problems having the same origin and attributes but differing in other aspects, such as scope and scale, will be discussed at a later stage. Lastly, DT seems to find solutions with a rather practitioner based approach, contrary to the transdisciplinary research process which originates in science (Felt et al., 2016). All these similarities led me to the belief that the comparison of DT to the framework by Lang et al. (2012) is relevant.

Connections between sustainability and design thinking have, so far, recognized sustainability as a relevant aspect to the process of designing physical products, which is the origin of design (Deniz, 2016; Garcia & Dacko, 2015; White & Stewart, 2008). This concerns the importance of a designer's basic understanding of environmental sustainability to be able to make sustainable design decisions. In most cases, small changes in the design of a product can have far reaching impacts, such as the life-cycle of a product and the sustainable use of environmental materials (Deniz, 2016; Garcia & Dacko, 2015). So far, the design process has neither been analyzed with a focus on its applicability or merits for transdisciplinary research in SS nor for any other kind of SS research.

DT applies a solution-oriented approach to enable innovative solutions to complex societal issues, or wicked problems (Luchs, 2015; Meinel, Leifer, & Plattner, 2010; von Thienen, Meinel, & Nicolai, 2014). It is a concept with many descriptions, such as methodology for innovation (Meinel et al., 2010) or approach to innovation (Brown & Kātz, 2009). While I use the term *design thinking,* in other contexts different labels may be used for the same process. Additionally to various terms and description for DT, the organization and terminology for the design process can also differ widely depending on the organization executing it (see Table 1); however, the confusing terminology does not affect the execution of the process which is almost interchangeable in every organization (Cupps, 2014).

The application of DT in a diverse range of fields, such as education, health care, engineering, management, anthropology, or psychology highlight the flexibility and applicability of its process (Coleman, 2016; Dorst, 2011; Luchs, 2015; 2010). Businesses, such as Apple or Google successfully employ design thinking to be more innovative and establish their products in the market (Tim Brown & Wyatt, 2010). The public sector employs DT in a broad variety of fields from energy efficiency programs and neighborhood policing to family support, as it helps them to find solutions to social problems (Tim Brown & Wyatt, 2010). This shows that DT has grown beyond simply designing products, objects or things, into the realm of designing “socio-material assemblies” (Björgvinsson, Ehn, & Hillgren, 2012, p. 102).

Table 1. A comparison of the models of design thinking along common phases of discover, create, and build. Reprinted from (Cupps, 2014)



Design thinking offers a novel, creative approach towards problem solving (Luchs, 2015), contrary to scientific approaches using analytical thinking based on epistemology (Meinel et al., 2010). This is no accident and Shneiderman (2016) points out that DT does not want to be “scientized”. Design thinking simply wants to find solutions to problems, which are often very close to everyday life, without having to gain scientific knowledge (Lindberg, Meinel, & Wagner, 2010). Shneiderman (2016) argues that a combination of the scientific and design process may be best for the development of new insights and innovation. Design thinking as a profession should be seen as a “a comprehensive meta-disciplinary concept that broadens disciplinary reasoning” (Lindberg et al., 2010, p. 8), which can help scientists to escape the paradigms internalized during their academic training (Lindberg et al., 2010). Design thinking uses creativity to deal with problems instead of scientific representative or rationalized thinking methods (Lindberg et al., 2010).

The principles DT scholars follow, also called “key themes” (Young, 2010, p. 5), “mindsets” (Luchs, 2015, p. 9) or “rules” (Meinel et al., 2010, p. xiv), are a agreed precondition for a successful design process:

- Human-centered: Every solution must always be human-centered, rather than tackling design challenges from organizational or technical frames. Designers aim to satisfy human needs with a product, which are often thousands of years old, with only the technological and social environment changing around them.
- Research-based: Qualitative, ethnographic and observational research techniques applied in support of design challenges.
- Broader contextual view: Expanding the problem space to a wider frame of reference, to examine the system and context in which design challenges exist. This requires holistic and integrative thinking towards ideas from other fields.
- Collaborative: Exploratory approach to problem-solving in a multi- or interdisciplinary environment. Usage of methods which encourage participation from broad array of stakeholders for a wide variety of ideas and opinions toward solution finding.
- Ambiguity and flexibility: Designers need to feel comfortable with ambiguity and flexibility in content and approach. Preserving ambiguity and avoid any kind of limiting effects while experimenting. Being comfortable with testing ideas, prototypes, and failure. The ability and willingness to work in different modes: verbal, visual and tactile.
- Iterative delivery & prototyping: Use of iterative project management approaches and prototyping, incorporating rapid feedback loops to evaluate and evolve ideas and prospective designs.

Finally, I will introduce some key terminology that I will use in this thesis in the context of DT.

The **design methods** are the methods and approaches employed by designers within the design process (Cupps, 2014). They include physical tools, such as pen and paper, post-it notes, whiteboard, puppets to represent actors or software tools with graphics and visualizations (Chasanidou, Gasparini, & Lee, 2015). However, the application of design methods is not the focus of this research.

The **design process (DP)** is the framework bringing all the design methods together into a systematic, repeatable process (Cupps, 2014).

The term **designer** refers to the way members work in a team, which is usually by exploring and solving problems through iteration (Luchs, 2015). In my thesis, a designer is anyone within the DT process: practitioners, researchers, scientists.

When using the term ***product*** in my thesis, in the context of DT or SS, it refers to the outcome of the project (if not stated otherwise): examples are software, hardware, policy, physical object or an improved process.

The term **(end-) user** is used to describe the people for whom the solution of the project is intended.

Divergent thinking is a creative method used when multiple potential solutions need to be generated in a short amount of time while keeping other constraints in mind (Cupps, 2014). Common methods used are brainstorming, sketching or story-mapping, which all encourage creativity and ideation (Cupps, 2014). This method is usually used in combination with convergent thinking (Cupps, 2014).

Convergent thinking is a method used when a number of possible answers to a problem were found and need to be converged into fewer options (Cupps, 2014). Pre-determined constraints are used to organize them and find commonalities (Cupps, 2014). This method is usually used in combination with divergent thinking (Cupps, 2014).

Divergent and convergent thinking are used to explore the **problem space** and **solution space** in the DP (see Figure 1).

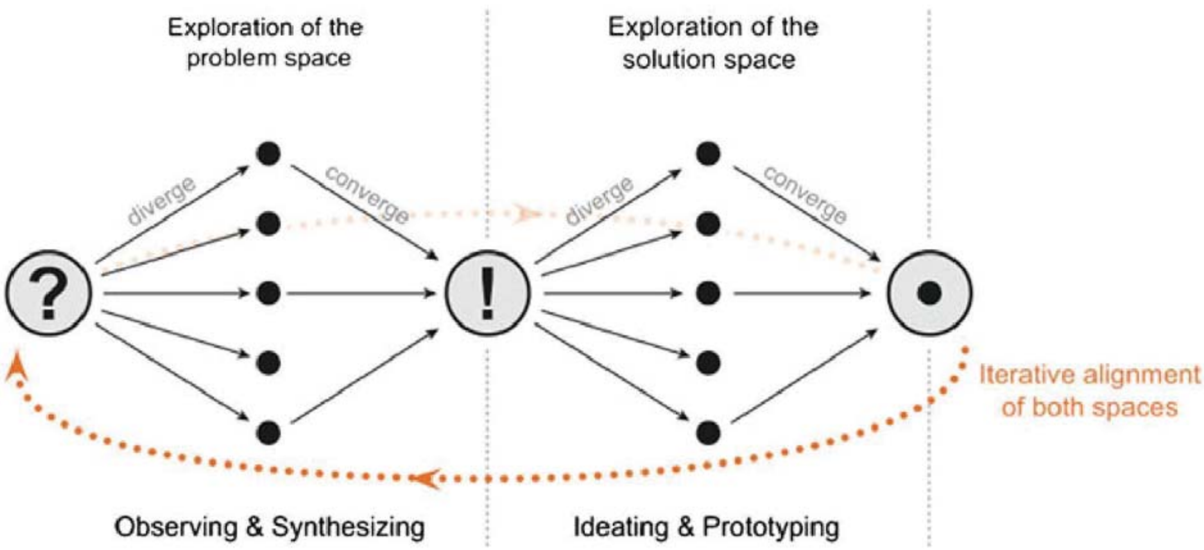


Figure 1. Problem and solution space in the design process. Reprinted from (Lindberg et al., 2010)

1.4 Aim of Study and Research Question

Transdisciplinary research is the future of SS but its implementation is complicated. The overall aim of my thesis is to support the advancement of theoretical transdisciplinary frameworks. In order to achieve this advancement, I will compare the framework by Lang et al. (2012) with design thinking and analyze their differences to find points of improvement for the transdisciplinary. Another aim is to establish a first connection between the two fields of research. As I employ an explorative research, I will look for points of improvement beyond those already identified. This leads to my overarching research question:

- To what extent can design thinking support the advancement of the theoretical transdisciplinarity frameworks in sustainability science?

To answer this research question, I need to find out in which ways DT could advance the transdisciplinary framework. To find this out, I will ask the following sub-question:

- How can design thinking support the advancement of the theoretical transdisciplinarity frameworks in sustainability science?

2 Methodology

2.1 Qualitative Research

To answer my research questions, I will compare the transdisciplinary framework by Lang et al. (2012) with several approaches found in DT. My research strategy is qualitative research. The research design is to go through the transdisciplinarity framework, compare it to design thinking and analyze the differences in regards to potential improvements for the transdisciplinary framework. As this is the first time any frameworks of design thinking and transdisciplinarity are compared, I chose a qualitative approach. This is appropriate due to the explorative nature of my thesis and the open research question (Silverman, 2010).

I used the same data selection method for the collection of my background research and comparison section. The data for the SS part is journal articles, research articles, SS textbooks and SS PhD theses. The data for the DT part is journal articles, research articles, DT textbooks, DT theses, and process guides. Except for two books from the library of Lund University, all the sources were found online. The sources used for my SS research were found and can be accessed via the online library of Lund University. The search string included the following terms or a combination thereof: sustainability science, transdisciplinary sustainability science, transdisciplinary research, sustainability science research process. The sources for DT were found and can be accessed via the online library of Lund University, Google Scholar, as well as the homepages of the Hasso Plattner Institute of Design at Stanford University and the DT company IDEO. The search string included the following terms or a combination thereof: design thinking, design process, design thinking and sustainability science, design thinking and wicked problems.

Some level of subjectivity can never be removed from any research, especially, qualitative research (Bryman, 2012). In my case, this concerns the bias of data selection and interpretation. However, there are important factors which can raise the quality of qualitative research. Replicability and validity are concepts developed for quantitative research but can be adapted to qualitative research (Bryman, 2012). The replicability of qualitative research is usually hindered by several factors: the focus of the researcher on certain aspects over others when collecting data, subjective analysis of the data by the researcher, and subjective data gained from external actors (Bryman, 2012). The replicability of my thesis is given if the texts stay available in the databases. The clear structure of the data in my comparison section minimizes personal influence, but cannot eliminate it. No external actors or subjects were involved in the collection of data, which removes this hurdle for replication.

The validity of my research is about the integrity of my conclusions. The internal validity of my research concerns the causality of my research, in other words, if the causal relation between the transdisciplinary and DT frameworks would hold true if applied in real life research (Bryman, 2012). One possible problem with validity is the bias of the researcher to choose examples which fit their reasoning (Silverman, 2010). The external validity questions the applicability of my findings in other contexts (Bryman, 2012; Silverman, 2010). The extent to which internal and external validity are given is analyzed in the discussion chapter.

In my research, I will take a constructionist ontological stand. This means that I see the properties of the frameworks as shaped by the interaction of the individuals within it, instead of being pre-defined (Bryman, 2012). The process is produced, and constantly reviewed and reshaped by the team (Bryman, 2012). This means that the hierarchies and roles of the team members are less prescribed but more assumed by the individuals and then filled in (Bryman, 2012). These patterns of role allocations, therefore the structure of the organization will be shaped by visible and invisible negotiations between the actors (Bryman, 2012).

2.2 Concept

I use the framework by Lang et al. (2012) to represent transdisciplinary frameworks in SS (see Figure 2). As can be seen in Figure 2, the framework consists of three phases. These are broken down into several design principles. Design principles are practice-oriented guidelines, rather than specific instructions, of how to conduct transdisciplinary research in SS and they describe how to carry out the three phases (Lang et al., 2012). They cover the guiding questions, realization, and challenges of the research process. The design principles will serve as a structure for my comparison and represent the 'ideal' transdisciplinary research process in SS. Although the steps and the overall framework are presented in a linear manner, they are to be carried out iteratively and recursively (Lang et al., 2012). In each step of the comparison, I will give an overview of the design principles by Lang et al. (2012) before giving an overview of the equivalent step of DT (if existent).

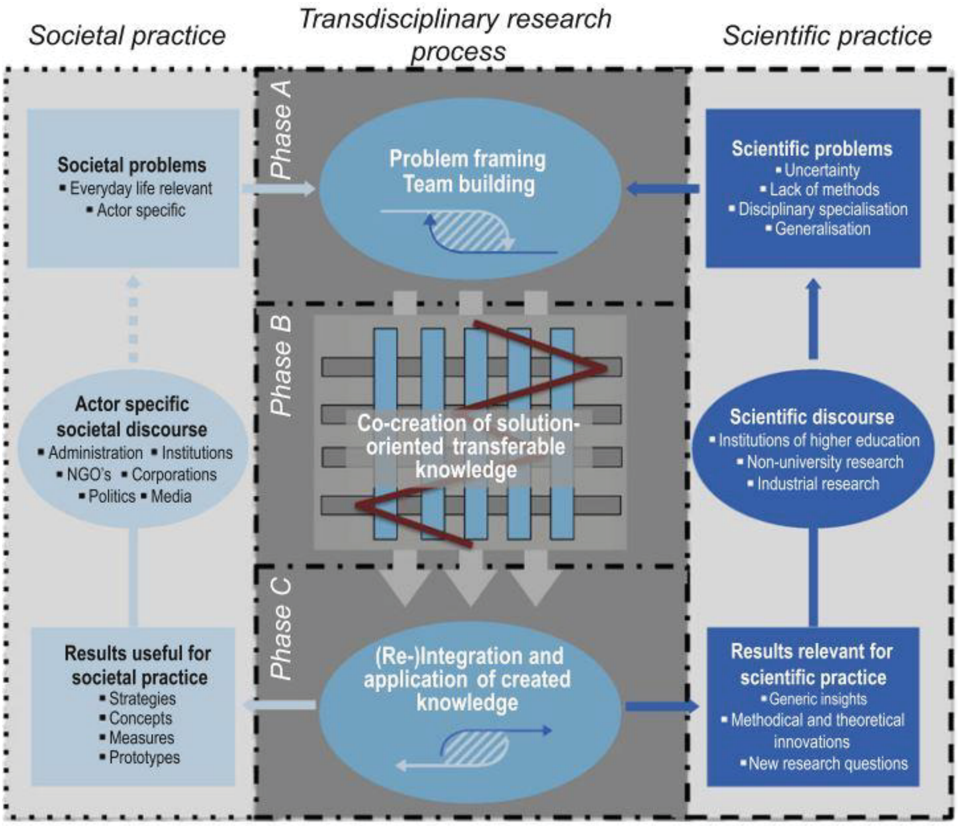


Figure 2. Conceptual model of an ideal-type transdisciplinary research process. Reprinted from (Lang et al., 2012)

For a visual representation of the DP, I chose the framework by Cupps (2014) (see Figure 3). It is also divided into three phases which are sub-divided into steps, which roughly corresponds to the conceptual framework by Lang et al. (2012). It also stresses the iterate nature of the DP with no clear starting or ending. However, the framework by Cupps (2014) only serves as a visual representative for the DP, while information about the individual steps is taken from several DT scholars and frameworks.

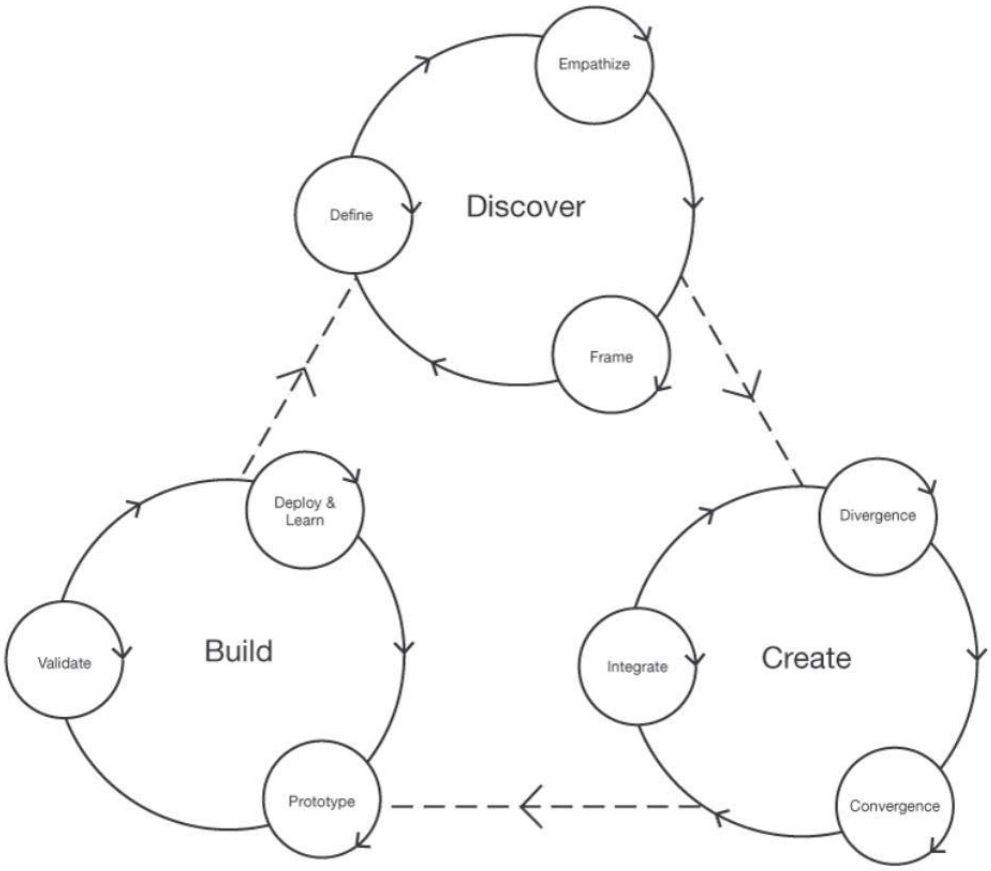


Figure 3. Design Process, including three phases and nine steps. Reprinted from (Cupps, 2014)

3 Introduction to and Comparison of Frameworks

3.1 Phase A: Design Principles for Collaborative Problem Framing and Building a Collaborative Research Team

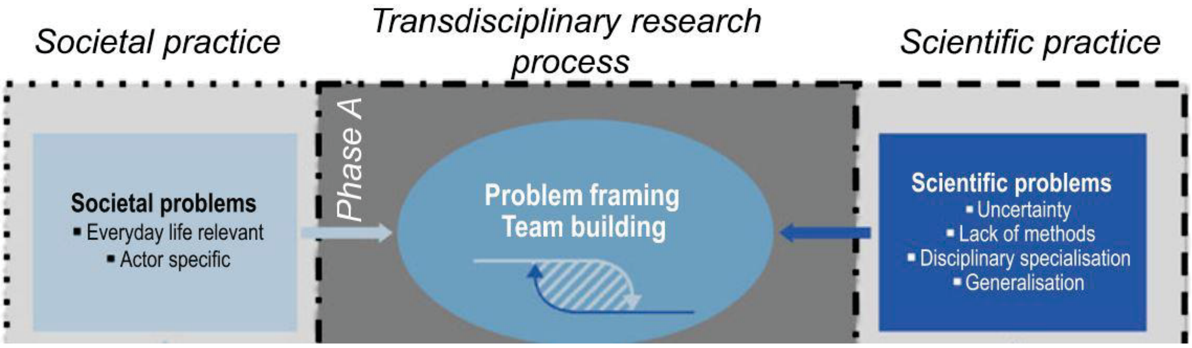


Figure 4. Phase A of the transdisciplinary research process, including societal and scientific problems in the problems framing and team building. Adapted from (Lang et al., 2012)

3.1.1 Build a Collaborative Research Team

The first step in the framework by Lang et al. (2012) is to build a research team consisting of stakeholders relevant to the research problem. This includes scientists from different disciplines, practitioners and end-users (Lang et al., 2012). After defining a problem in the next step, this first step can be repeated to keep the constellation of the team relevant to the research problem (Lang et al., 2012). Therefore, step one and two can overlap (See center of Figure 4) To form a working research team, team building exercises and organizational structures, including responsibilities, and a 'common language' should be developed (Lang et al., 2012).

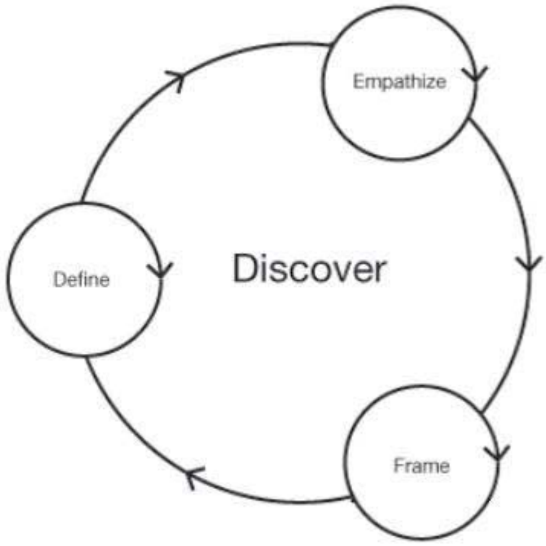


Figure 5. Discovery phase of DT, including the steps define, empathize and frame. Adapted from (Cupps, 2014)

The equivalent step in the DP is to assemble an interdisciplinary team with stakeholders related to the process and, if possible, a multidisciplinary background (Tim Brown & Wyatt, 2010). Every member needs to add a certain knowledge, expertise or relevance to the project while also being able to work in a group. Lindberg et al. (2010) describes these individuals as T-shaped: horizontally, including other members and able to look for new opportunities; and vertically, having thorough knowledge within their field of expertise and the ability to include it in the process. No further evidence on the team constellation could be found in the literature. However, the origins of DT and current employment in the private and public sector suggest that the process is usually initiated by practitioners rather than scientists (Tim Brown & Wyatt, 2010). Design thinking does not provide a common working language from the start as the many versions of DT all use different terminology, which means that a common language needs to be developed for the project (Cupps, 2014).

3.1.2 Create Joint Understanding and Definition of the Sustainability Problem to be Addressed

The second step of phase A is to define the sustainability problem, not just as any complex problem, which problem relevant to society "that implies and triggers scientific research questions" (See left and right column in Figure 4) (Lang et al., 2012, p. 29). Every member should be participating in the problem definition (Lang et al., 2012). The problem must be balanced between "normative scientific and political claims of importance and relevance" (Hadorn et al., 2008). The problem formulation is to make sure that the following research departs from the same point of reference (Lang et al., 2012).

In the DP, this is comparable to the step *define* (see left circle in Figure 5) in which the designers are trying to understand the current situation and define a problem space (Cupps, 2014). Even if a problem definition is already given, DT encourages the designers to redefine the initial problems statement to find the most important aspects to solve first and find alternative solutions, instead of only modifying existing products (Chase, 2016; Luchs, 2015).

3.1.3 Collaboratively Define the Boundary/Research Object, Research Objectives as well as Specific Research Questions, and Success Criteria

After defining the sustainability problem, the research objectives, boundaries, questions and success criteria need to be established (Lang et al., 2012). This helps to monitor the research progress and adjust research activities throughout the process (Lang et al., 2012). The outcome of this definition should be a well-defined guiding research question, accompanied by specific sub-questions (Lang et al., 2012). The research objectives should include the different interests of scientists to advance scientific knowledge and of the practitioners to solve the real-world problem (Lang et al., 2012). Especially, scientists need to be aware of potential role conflicts throughout the process as their responsibilities multiply (Lang et al., 2012). These steps are important prerequisites for finding an appropriate design for the methodological framework. Lastly, success criteria should be defined to help to evaluate the project after completion (Lang et al., 2012).

The DP does not narrow down the problem yet but is instead using divergent thinking to keep options available for the designers at a later stage of the process (Lindberg et al., 2010). After defining a problem statement in the previous step, the DP is now filling this space with user-insight. As DT is human-centered and its main aim is to find solutions for the end-user, the DP must keep their needs in focus (Young, 2010). The DP can be supplemented with user-insight from surveys or other traditional methods, but they are not the main methods used as they rarely lead to groundbreaking innovation (Tim Brown & Wyatt, 2010). Instead, designers immerse themselves in the setting of the end-user to observe and understand their context, behavior, experience, actions, values, beliefs, thoughts, and desires (see top circle in Figure 5) (Luchs, 2015; Stanford, 2010; 2010). Using convergent thinking, meaning is extracted from the user-user insights. To begin the convergent thinking phase, the designers develop a frame of boundaries to the possible solutions that can be developed in the next phase (see bottom circle in Figure 5) (Cupps, 2014). This is necessary, to avoid too broad or manifold problem statements for the next phase. The frame includes a definition of what success will look like and three constraints:

- desirability - is this what we need and does it make sense,
- viability - do we have the means to do this sustainably, and
- feasibility - do we have the expertise and technical basis to make it happen (Cupps, 2014)?

The outcome of the convergent thinking phase can be several sets of problem statements which, if necessary, can be further reduced until a previously defined appropriate amount of problem statements has been reached (Luchs, 2015). These first three steps of the DP may be already iterated at this point to find the best team, user insights, framing, and problems statement (see Figure 5).

3.1.4 Design a Methodological Framework for Collaborative Knowledge Production and Integration

Prepare for Phase B by agreeing on a "set of methods and transdisciplinary settings to be applied in Phase B" (Lang et al., 2012, p. 32). The research methods need to be in strong accordance with the research question and must support collaboration and integration throughout the project (Lang et al., 2012). To achieve this, previous methodological knowledge about transdisciplinary research should be considered (Lang et al., 2012). A common framework is to provide guidance for each team member, which may be adjusted throughout the research process (Lang et al., 2012).

Design thinking is described as a methodology for innovation itself by some scholars (Meinel et al., 2010); (Camacho, 2016). The collaborative aspect of DT is already manifested in its core aspects (Young, 2010). The DP comprises of an endless amount of design methods which are to be applied in the individual modes of the design process (Cupps, 2014). Which one is appropriate to use is decided by the team or facilitator in a flexible way. Every iteration of the process may ask for a different set of methodology.

3.2 Phase B: Design Principles for Co-creation of Solution-Oriented and Transferable Knowledge Through Collaborative Research

3.2.1 Assign and Support Appropriate Roles for Practitioners and Researchers

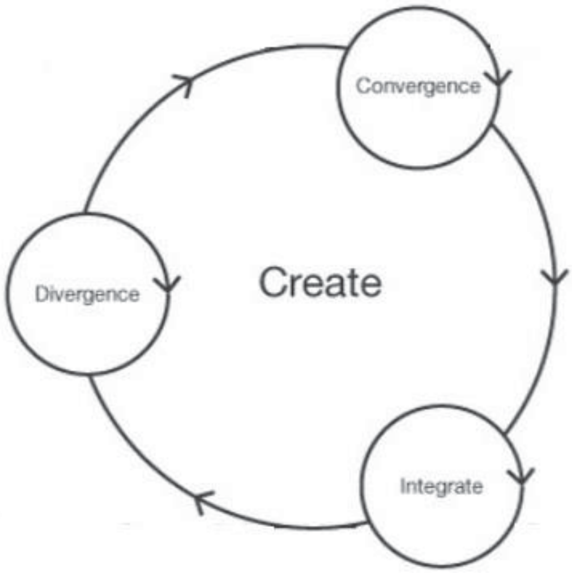


Figure 6. Create phase of DT, including the steps divergence, convergence and integrate. Adapted from (Cupps, 2014)

The scientists and practitioners are given appropriate roles and responsibilities, keeping "inertia, reluctance, and structural obstacles" (Lang et al., 2012, p. 32) in mind. The assignments have to be according to the framework, guidelines and organizational structures defined in Phase A (Lang et al., 2012). Lang et al. (2012) highlight the emerging difficulty for the scientists to balance the societal relevance and scientific rigor; while, the process has to enable participants to fulfil their roles/responsibilities and participate. Good leadership of the transdisciplinary process is needed to ensure that the knowledge of all actors is included and coordinated, and disagreements are resolved (Lang et al., 2012).

The DP does not have an equivalent step to this design principle. This is due to the unknown team composition mentioned in the first step of Phase A. The only role assigned in the DP is a team leader or facilitator, experienced with the DP, if the team is new to the concept of DT (Luchs, 2015).

3.2.2 Apply and Adjust Integrative Research Methods and Transdisciplinary Settings for Knowledge Generation and Integration

Based on the methodological framework developed in Phase A, the team uses and further develops methods which are appropriate for transdisciplinary sustainability research (Lang et al., 2012). In this phase, it is important to use tools which support teamwork and collaboration between all participants to make sure that the quality of transdisciplinary research is given (Lang et al., 2012). This can help to improve participants access to research results and achieve the team's full potential to "further develop existing or develop novel methods for transdisciplinary knowledge production and integration" (Lang et al., 2012, p. 32).

The DP starts to generate ideas based on the problem statements from Phase A to look for solutions or opportunities for change (Luchs, 2015; Tim Brown & Wyatt, 2010). These in mind, the designers start the process of divergent and convergent thinking again (see left and top circle in Figure 6). In the divergent thinking phase, the team creates as many ideas as possible by going to the limits of imagination and beyond obvious solutions, instead of, trying to find a single best solution (Coleman, 2016; Stanford, 2010). It is important to defer any judgement towards created ideas to keep the creative flow going in terms of fluency (volume) and flexibility (variety) (Cupps, 2014). This creative process can also overlap into the step of prototyping (see section 3.3.2) by using simple prototypes to make ideas more tangible instead of contemplating them with words (Skogstad & Leifer, 2010). Following, convergent thinking is applied by questioning if the created ideas fit the constraints (Cupps, 2014). The intersection of the constraints is where innovation is usually happening in DT (see Figure 7).

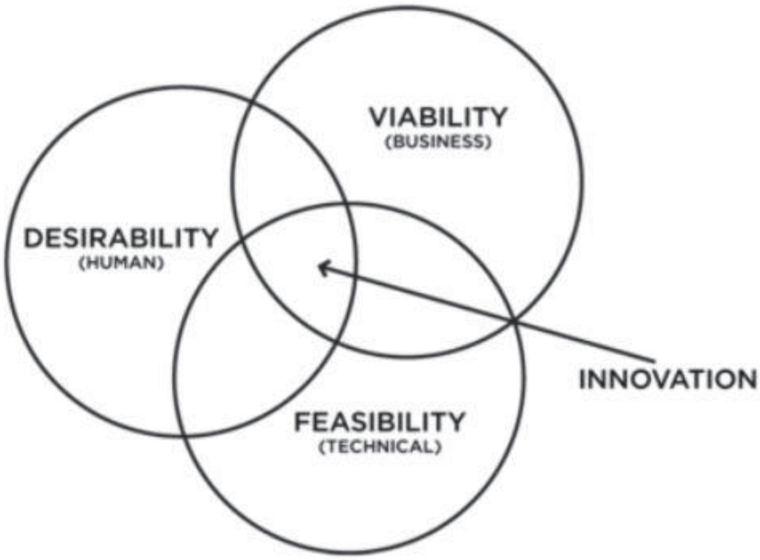


Figure 7. Innovation happens at the intersection of desirability, viability and feasibility. Taken from (IDEO, n.d.)

The ideas are tested against each other to find the best ones (Tim Brown & Wyatt, 2010). Alternatively, the ideas are integrated by finding that multiple, even opposing ideas, to the same problem can lead to a combined solution (see bottom circle in Figure 6) (Cupps, 2014). As can be seen in Figure 6, the steps of Phase B can also be iterated before moving to Phase C.

3.3 Phase C: Design Principles for (Re-Integrating and Applying the Created Knowledge)

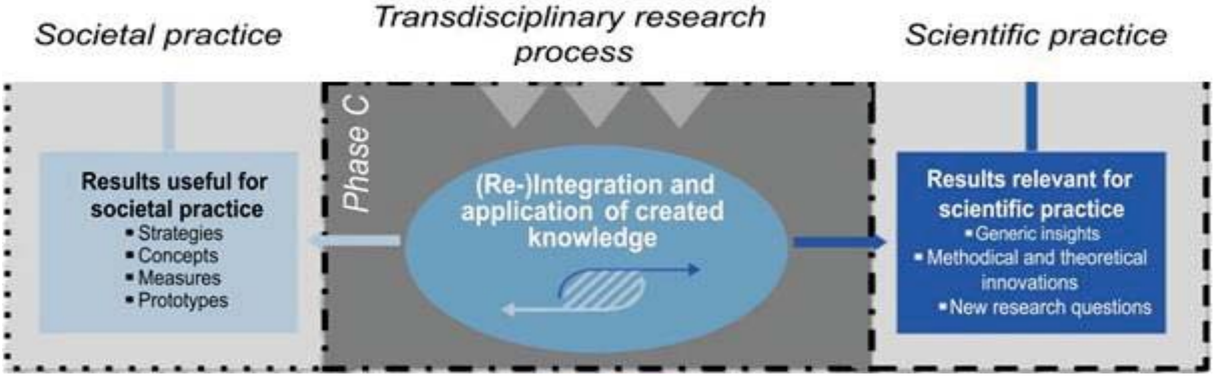


Figure 8. Phase C of the transdisciplinary framework in which the outcomes are (re-)integrated in the societal and scientific practice. Adapted from (Lang et al., 2012)

3.3.1 Realize Two-Dimensional (Re-)Integration

The outcomes of Phase B are reviewed and revised from the societal and scientific perspective, uncovering the mutual learning process (see center in Figure 8) (Lang et al., 2012). This process needs to be done by using different criteria for both perspectives, as both "adhere to quality criteria such as scientific credibility or practical applicability (saliency) differently" (Lang et al., 2012, p. 34).

The DP does not feature this kind of intermediate revision as the evaluation step (see step 3.3.3) fulfils this role.

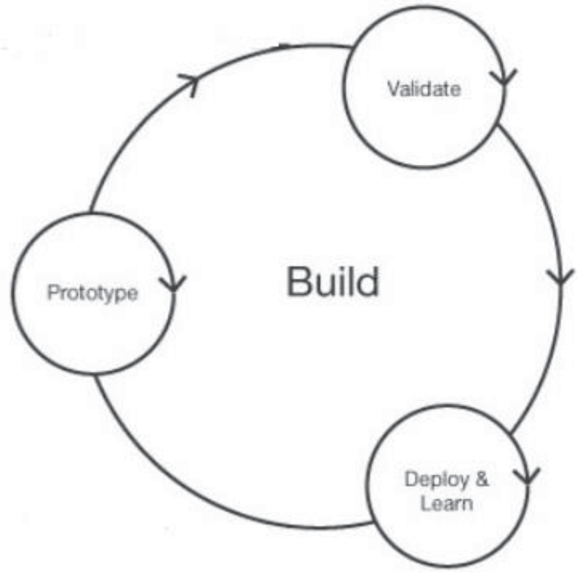


Figure 9. Build phase in DT, including the steps prototype, validate and deploy & learn. Adapted from (Cupps, 2014)

3.3.2 Generate Targeted "Products" for Both Parties

Give the scientific actors and practitioners the solutions generated in Phase B which they can present and translate into results and make use of in their respective field: "scientific progress/innovation or real-world problems solving/transformation" (see left and right column in Figure 8) (Lang et al., 2012, p. 34).

The DP starts Phase C by prototyping (see left circle in Figure 9) (Tim Brown & Wyatt, 2010). Prototypes can help to find unintended or unforeseen challenges to the product (Tim Brown & Wyatt, 2010). It helps the designers to communicate and interact with the users and gain valuable first hand feedback by observing the user interaction and seeing if the solution works (Cupps, 2014; Luchs, 2015). Even if the end-user is part of the research team, this step cannot be skipped as the product needs to be validated by external users: “the design team is never the user – ever” (see top circle in Figure 9) (Cupps, 2014, p. 61).

The prototypes itself should be ‘low-res’ and follow three simple principles: fast, disposable, and focused. Fast prototyping means spending little time on developing prototypes allows a faster iteration of the process (Tim Brown & Wyatt, 2010). Disposable describes that prototypes should be elaborated enough to communicate the idea to the user - not more (Tim Brown & Wyatt, 2010). Focused means using the prototype to present the aspects which need the most testing or are unknown (Tim Brown & Wyatt, 2010). These rules ensure that the team can pursue different ideas and fail quickly and cheaply, without committing to one too early (Stanford, 2010). The prototypes can be unfinished, have little to do with the final product, be made of a simple cardboard construction, 3D-printed, be a role play, or more elaborate software interface; whatever is needed to communicate the idea to the user (Cupps, 2014; Garcia & Dacko, 2015; Luchs, 2015; Tim Brown & Wyatt, 2010). With a bit of creativity, almost everything can be prototyped: government policies, transport system, or retail store designs (Gravina & Saunders, as cited in Young, 2010). In the first few iterations of the process the prototypes only serve to gain insights, while the later ones will become more and more complete (Tim Brown & Wyatt, 2010).

3.3.3 Evaluate Societal and Scientific Impact

After completion, the project is evaluated to show which impact it had and lessons can be learned for future projects (Lang et al., 2012). The success criteria defined in Phase A, or adapted versions, serve as guide for societal and scientific outcomes of the project (Lang et al., 2012).

The designers deploy the prototype to the end-user to get feedback and have another opportunity to empathize with them (Stanford, 2010). The evaluation is important to get input for the final product, rather than an evaluation of the final product itself (Luchs, 2015). Testing the prototypes in the most realistic context and as interactive as possible will yield the best feedback (Stanford, 2010). It will help to inform future decisions and the next iteration of solutions and prototypes (Young, 2010). The information gained from the evaluation is synthesized and used for the next iterations; thus, it can be seen as an expansion to the discovery phase of DT (Luchs, 2015). After every iteration of the DT process, the ideas and solutions should become more narrowed down (Stanford, 2010). Therefore, a repetition of these four steps is mandatory in DT until the team is confident to have found the best solution. When the DT process has been iterated enough times and the solution seems promising it can be deployed (Luchs, 2015). The production of the solution may then be in a rather linear ‘traditional’ fashion (Luchs, 2015). After deployment, the success is measured according to the success criteria defined in Phase A (Cupps, 2014). Even after this final deployment, the insights gained from active long time use can be used in the next iteration of the process (Cupps, 2014). As can be seen in

Figure 9, Phase C can be iterated by directly developing new prototypes from the end-user feedback. Following, the whole process Phase A to Phase C is iterated (see Figure 3).

3.4 General Design Principles Cutting Across the Three Phases

The cross-cutting principles presented by Lang et al. (2012) are not specifically accounted for in DT but the aspects are included in the phases.

3.4.1 Facilitate Continuous Formative Evaluation

Lang et al. (2012) propose formative evaluation throughout the process. Formative evaluation describes the review and evaluation during a process, instead of evaluating a process at its end. In the framework by Lang et al. (2012) this is done by external scientists or practitioners. This allows the change of the subsequent steps in the process (Lang et al., 2012).

The inclusion of external actors happens in Phase A and C of the design process. The evaluation in Phase C helps the designers to review, reshape and redesign the problem and solution space. Therefore, DT uses formative and summative evaluation. Formative evaluation is used as the evaluation in the design process is just one step within the iterative framework which starts all over after the evaluation step. However, summative evaluation is also used as the prototype can be used to measure the success of the product between expected and actual outcome. Although members should stay consistent throughout all iterations of the project, the occasional inclusion of 'outsiders' in the project, in steps other than evaluation, can be beneficial for new and unexpected insights (Luchs, 2015; Young, 2010).

3.4.2 Mitigate Conflict Constellations

The integration of scientists from different disciplines and practitioners can lead to conflicts (Lang et al., 2012). Team meetings, open group discussions and other mediated negotiations can help to mitigate conflicts (Lang et al., 2012). It is important that carefully designed agreements are made at the beginning of the project and then followed or adapted throughout (Lang et al., 2012).

The DP tries to use individuals who can work in groups. However, the problems highlighted above can never be fully avoided.

3.4.3 Enhance Capabilities for and Interest in Participation

In projects that might continue for months or years, the continued participation of all members cannot be presumed (Lang et al., 2012). The resources, such as time, money and energy, which need to be invested in successful participation throughout the project may be underestimated or unattainable by some actors (Lang et al., 2012). This highlights the importance of selecting accessible meeting locations and times, as well as enabling and motivating everyone to participate through high levels of interactivity and incorporating visually stimulating aspects (Lang et al., 2012). This can help to bridge the gap between members in terms of different backgrounds, languages or levels of knowledge (Lang et al., 2012).

The location or timeframe can create the same problems in the DP. The DP stresses the importance of interactivity and makes sure that every member has the chance to and is in fact actively participating in the process.

4 Analysis

This section is structured along the three phases of the framework by Lang et al. (2012). The cross-cutting design principles are incorporated in the three phases.

4.1 Phase A

The first step in both frameworks is to assemble a research team. In the 'ideal' transdisciplinary research process it is important that the societal and scientific branch are both represented to guarantee a positive outcome for both parties; furthermore, the people affected by the study, or end-users, must be included (Lang et al., 2012). This collaborative team is to work together throughout all steps of Phases A to C (Lang et al., 2012). Hillel (Bernstein, 2015) argues that in some cases transdisciplinary research can also be executed by an individual by combining the knowledge from several disciplines and engaging with practitioners. The size of the research team and level of inclusion of practitioners by scientists is a complex matter and discussed in more detail by Jahn et al. (2012) and Brandt et al. (2013). Design thinking has vague guidelines on including practitioners or scientists in the team. The main criteria for the member selection is that they are T-shaped and relevant to the problem (Lindberg et al., 2010). Considering the inclusion of the end-user, there is a significant difference to the transdisciplinary process. End-users are used for external feedback in the DP. So, as soon as an end-user joins the design team, they lose their end-user status (Cupps, 2014). One aspect to keep in mind concerning the inclusion of end-users is highlighted by Björgvinsson et al. (2012) who state that the end-users are not always easily identifiable, which is relevant for both processes.

A challenge to transdisciplinarity highlighted by Lang et al. (2012) and affecting the whole process is the question of power relations within the team. The transdisciplinary process in SS is usually initiated by scientists, which leads to bias problems from initial problem framing to the selection of practitioners for the project (Jahn, 2008; Lang et al., 2012). Also, the decision making concerning the research location and ownership of the problem is biased towards the scientists (Felt et al., 2016). Looking at power from a communications point of view we can understand that power is the foundation for understanding of what comes to be seen as possible within a process (McGreavy et al., 2013). For more information on power relations in a transdisciplinary process read McGreavy et al. (2013). The literature on DT does not offer any improvements or solutions to the power challenges in the transdisciplinary process as the power relations in DT are unclear as well.

Depending on the level of integration and given problem (see Jahn et al., 2012 and Brandt et al., 2013), the exclusion of end-users from the research team may have certain advantages. Lang et al. (2012) highlight some challenges in their cross-cutting design principles. They point out that scientists need to find a location, mode of communication, timeframe and methodology supportive of the integration of every member of the team, while motivating every team member to stay engaged. The more diverse the research team is the more difficult this becomes. I argue that the inclusion of the end-user in cases of disparate language, working culture, or other aspects between the research team and end-users may not be beneficial to the research process overall. As the end-user is only included to represent their point of view to the research team, the DP may be more efficient. The DP may be able to get the same beneficial information without having to include the end-user throughout the whole process. By only including the end-user in the empathize and evaluation steps of their research, the designers are possibly simplifying and speeding up their research in Phase B.

In the second step, the teams create an understanding of the problem the project is addressing. The sustainability problem in transdisciplinary research is required to be societally and scientifically relevant (Lang et al., 2012). However, Jahn et al. (2012) point out that priority can be given towards the societal or scientific progress in research practice, depending on the given problem. DT is more flexible with its problem space as it aims at finding solutions for the problems given: science, society, or both. While the framework by Lang et al. (2012) does not provide any guidelines on how to define the sustainability problem, Jahn et al. (2012) suggest that a problem transformation is happening when societal problems are the starting point for scientific research. By using reflexive methods to define the sustainability problem it is transformed into a scientific problem (Jahn et al. 2012). DT starts by taking a step back and redefining the problem (Young, 2010). This way, the DP ensures that the most important problems are targeted first and enables the team to look for solutions beyond the initial problem statement (Tim Brown & Wyatt, 2010). Skipping this step and using the initial problem framing may lead to assumptions that cause the team to miss an innovative opportunity. The framework by Lang et al. (2012) could integrate this DP step of critically questioning in its framework to advance problem understanding.

In the third step, both frameworks take very different approaches. The transdisciplinary framework aims at narrowing down the research objectives, boundaries, specific research questions, sub-questions, and success criteria (Lang et al., 2012). These need to include the interests of scientists and practitioners (Lang et al., 2012). According to the framework by Lang et al. (2012), this is relevant as the methodological framework and the rest of the project depends on these early definitions. DT does not develop a research question but develops several problem statements in this step. At this point, DT uses divergent thinking to fill the problem space with user-insight. This is done by empathizing with the end-user (for details see section 3.1.3) (Cupps, 2014). Following, convergent thinking is used to turn the user-insight into a problem statement (for details see section 3.1.3) (Cupps, 2014). This highlights the difference between the inclusion or exclusion of the end-user in the research team once again. According to Lang et al. (2012), the ‘ideal’ transdisciplinary research process gains user-insight by integrating the end-user in their team; the designers need to empathize with the end-user to gain user-insight. Having the end-user on the team or empathizing with them in their natural context may lead to different insights. The end-users in the transdisciplinary framework may already be influenced simply by their inclusion in the research team. The designers should get less biased and more valuable user-insights on the end-user's needs and wants. Without limiting the transdisciplinary framework by Lang et al. (2012), it could integrate parts of DT for a better user focus of the product. Empathizing with end-users external to the research team can be carried out with or without end-users in the research team. When these user-insights are synthesized at the end of this step the transdisciplinary framework could still end up with a single research question. Ending up with several problem statements leaves the team with more options in the next step but may also exceed the project's capacities. This will be further discussed in the results section. Both frameworks describe the iterative process within Phase A in similar ways to find the best possible team constellation, and problem understanding.

In the final step of Phase A, the transdisciplinary framework defines the methodological framework for Phase B. As DT is described as a methodology for innovation itself by some scholars, this step is difficult to analyze (Camacho, 2016). The selection of a methodology and methods has significant implications on the rest of the research process, such as the inclusion of highly iterative methods. These implications and the research of methodology is, however, not within the scope of my thesis, as I only lay the groundwork for a first understanding of DT's applicability and integration in the ideal transdisciplinary research process by Lang et al. (2012).

4.2 Phase B

In Phase B, the solutions are to be developed. In the transdisciplinary process framework by Lang et al. (2012), the generation of solutions is solely based on the methodology developed in Phase A (Lang et al., 2012). The only additional guidelines given by the framework are that every participant should be included in the transdisciplinary research, and the team's full potential is to be developed to produce knowledge and solutions (Lang et al., 2012). No instructions are given on how these steps are to be implemented. At this stage, the transdisciplinary framework limited itself to a specific research question, work allocation between members and methodological framework. In comparison, the DP is left with more options for the solution-finding step. Using the problem statements from the previous phase, the DP uses divergent thinking to develop numerous ideas and explore the solution space (Lindberg et al., 2010). Following, convergent thinking is used to narrow down the ideas. The DP encourages the designers to take several ideas into the next stage of prototyping. Several ways of defining which solution ideas can be taken to the next step exist, such as "the most likely to delight, the rational choice, [or] the most unexpected" (Stanford, 2010, p. 4). This means that the transdisciplinary framework takes one solution to Phase C while the DP process carries over several. It seems feasible to integrate divergent and convergent thinking within the transdisciplinary framework as it would not limit its applicability and flexibility towards solution development.

Lang et al. (2012) describe two challenges concerning the development of solutions in Phase B. The first challenge is that many stakeholders have to agree on a solution that can lead to vague or ambiguous results; therefore, it could lead to different interpretations of the solution and cover up potential conflict. In a transdisciplinary process focusing on finding a specific solution that has to satisfy every stakeholder after its employed in Phase C, this is a legitimate concern. Lang et al. (2012) propose to make the results more tangible to mitigate this challenge, which is exactly what DT does. Fast prototyping to make the results more tangible and eliminate unwanted ambiguity is at the core of the DP and will be explained in Phase C (Skogstad & Leifer, 2010).

The second challenge to successful transdisciplinary research is, according to Lang et al. (2012), the fear to failure, leading to pressure and the "retreat to pre-packaged solutions" or the "knowledge-first trap" (p. 38). The 'knowledge-first trap' describes the idea that researchers can get stuck wanting to understand every aspect of a problem leading to endless research and postponing the implementation of any outcomes (Lang et al., 2012). Again, the solution proposed by Lang et al. (2012) to increase "researching-/learning-by-doing" (p. 38) is exactly what DT practices. Starting a project and learning during the execution of the process rather than mapping out every possible scenario beforehand is not only what Lang et al. (2012) suggests but what is at the core of DT (Skogstad & Leifer, 2010). Prototyping is even described as a "method of learning from failure, trial and error, or experimentalism" (Cupps, 2014, p. 119). If a prototype does not deliver the expected results, it is not a failure but just reveals changes that need to be made for the next iteration (Luchs, 2015). This philosophy of not being able to fail differentiates the design process from more linear approaches in which a product not fulfilling the desired outcome could be considered a failure (Cupps, 2014).

However, the testing of ideas in the field needs to be done with care and should be based on a certain level of knowledge to decrease the risk of implementing potentially harmful or irreversible prototypes. A further challenge of using this approach is that it requires a working environment allowing the team to fail and not requiring it to succeed on the first try (Skogstad & Leifer, 2010). Although prototypes are only introduced in Phase C of the DP, their importance becomes already visible in Phase B. This is due to the overlap between the two phases and the iteration of the DP. Finding solutions depends on knowledge gained from prototypes and prototypes are based on the developed solutions.

4.3 Phase C

The implementation of solutions is described very differently in both frameworks. While the framework by Lang et al. (2012) describes the implementation of solutions as the final step of the research process, the solution in the DP is only the trigger for point for further solution investigation. According to Lang et al. (2012), the transformational solutions for society and scientific progress for science, which were found in Phase B, are distributed and implemented (Lang et al., 2012). Instead of generating the final products, the designers develop prototypes (see 3.3.2 for details on prototyping). Additionally to the benefits of prototyping highlighted in the previous steps, prototypes help to find unforeseen or unintended challenges to the product, as well as give another opportunity to empathize with the end-user (Tim Brown & Wyatt, 2010). The end-user is included in the 'ideal' transdisciplinary research team, which may lead to the assumption that this step can be skipped. But as mentioned in Phase A, DT argues that this step can never be skipped as the end-user is an external actor, thus can never be part of the team as their perspective of the project and final product are biased by their inclusion in the team (Cupps, 2014). The external validation and feedback is especially important when developing solutions for a foreign environment, such as solutions provided from developed to developing countries where missing infrastructure, communication chains or other essential systems are lacking and create unexpected problems (Tim Brown & Wyatt, 2010). Seeing the user interact with the prototype helps the designers to gain valuable feedback and additional user insights, which supports the understanding of the user in the emphasize step in Phase A. This way of gaining feedback and user-insight is very effective: "If a picture is worth a thousand words, a prototype is worth a thousand pictures" (Stanford, 2010, p. 5). One possible problem with sustainability problems is that their complexity may make it hard to define the end-user, which would make it equally difficult for the transdisciplinary process and DP to include them (Björgvinsson et al., 2012). Prototyping fulfils a dual role of gaining feedback from end-users and supporting solution development by making ideas more tangible in Phase B (Jobst & Meinel, 2014). This skill of prototyping, so important for the DP, has to be learned in order to be successfully implemented (von Thienen et al., 2014).

Gravina and Saunders (as cited in Young, 2010) state that almost everything, from retail store design to governmental policies, can be prototyped. However, it is questionable if the design scholars had the complexity, scale and timeframes of sustainability problems in mind. This being said, DT is setting out to tackle one of the biggest sustainability problems of our time: climate change. An example of DT fighting climate change is the support of advancing concepts of greenhouse gas emissions reductions, such as developing concepts for capturing methane from landfills (Seddon & Ramanathan, 2013). Furthermore, DT can help to develop more energy friendly buildings (Cameron, 2015). Design thinking is breaking down bigger problems into several smaller ones that it can deal with. Whether this can be done with every sustainability problem is questionable. In sustainability projects, which deal with unpredictable long-term impacts and research processes lasting several years, prototyping may not be able to help. So far, the limits of prototyping have not been researched, and they are difficult to define for a field of research as diverse as SS. The diversity of sustainability problems and the lack of literature regarding the limitations of prototyping make it impossible to define criteria for the range of applications within the scope of my research.

Prototyping and evaluation are tightly connected iterated steps. New insights can lead to better prototypes, which lead to new user-insights. The framework by Lang et al. (2012) frames the implementation of the product and the evaluation as two separate processes. The evaluation of the project described by Lang et al. (2012) is limited to its impact after completion and the lessons learned for future projects (Lang et al., 2012). This can be described as slow iteration which follows through the center left and right parts of Figure 2 and gives rise to a new transdisciplinary research process starting on a new understanding of the initial problem (Jahn et al. 2012). The steps of the transdisciplinary framework are described linearly; however, Lang et al. (2012) highlights that it should indeed be used iteratively. The importance to iterate within the phases and steps of transdisciplinary research is also highlighted by other scholars (Brandt et al., 2013; Jahn et al., 2012; McGreavy et al., 2013). The iteration within transdisciplinary processes can also be furthered by the inclusion of iterative methodologies, such as transition management (Loorbach, 2007) or scenario design (Kishita, Hara, Uwasu, & Umeda, 2016). However, my research is limited to the advancement of theoretical transdisciplinary frameworks, which lack clarity in the communication of iterative cycles. Although the importance of iteration is being highlighted, the execution of iterative steps is left to the guidelines of methodologies. Due to an absence of peer-reviewed reviews on the execution of iteration in actual transdisciplinary research, the connection between iterative guidelines in frameworks, such as Lang et al. (2012), and actual transdisciplinary research is unclear.

DT has the inclusion of iterative cycles embedded in the guidelines and visual representations of its frameworks. An example is the strong connection between evaluation in Phase C and empathizing in Phase A closes the circle of iterative research in the DP. This connection is also stressed by the visual representation of the design framework either as '∞' (see Figure 10) or cycle (see Figure 3).

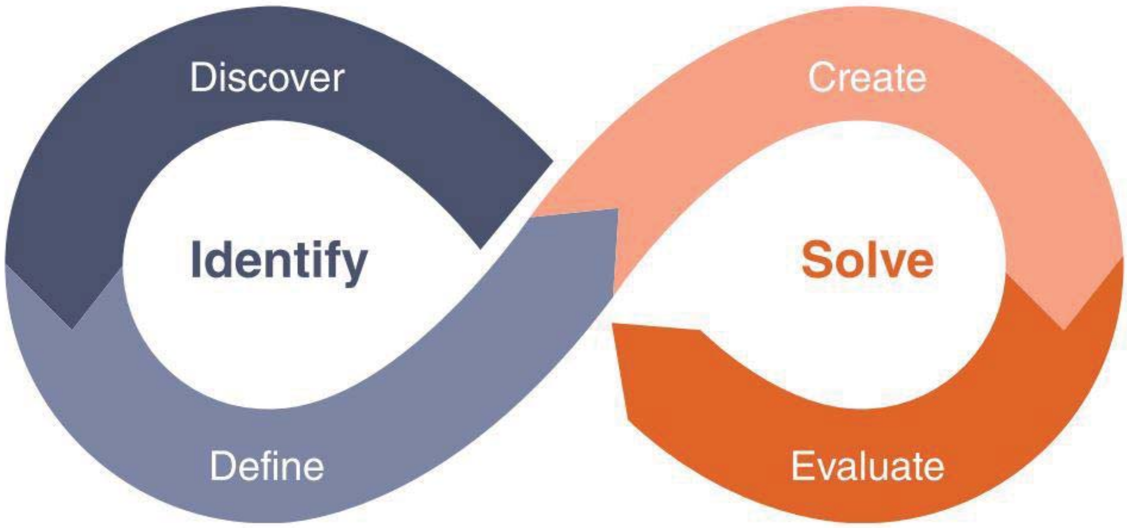


Figure 10. Framework of the design process. Reprinted from (Luchs, 2015)

To make the most of the prototyping and evaluation steps, they are to be employed in the most realistic context (Stanford, 2010). Convergent thinking is used one last time to synthesize the information from the evaluation for next iteration. Every iteration should lead to a more well-defined prototype until the team is confident to have found the best solution (Skogstad & Leifer, 2010). One issue pointed out by Lang et al. (2012) is that the result of the research may be misused for actions unintended by one side of the research team, scientists or practitioners. Prototyping and seeing the user, in this case scientist or practitioner, interact with the product may be able to avoid this to a certain point, but it can never be guaranteed that the final product is used in the same way as intended in the research process (Björgvinsson et al., 2012).

The cross-cutting design principle of *formative evaluation* described by Lang et al (2012) describes getting feedback from outsiders, experts or practitioners, at any point during the process to review and reshape the subsequent steps of the process. Apart from the final evaluation after the project has finished, this is the only external feedback. The evaluation step in the DP combines formative and summative evaluation, which makes this step so valuable for the process. As the transdisciplinary process does not propose the phase or format of the formative feedback, using the steps *empathize* in Phase A and *evaluation* in Phase D of the DP for feedback seems possible.

5 Results

I will present the results from the analysis of Phases A to C, which inherit a possible advancement for the transdisciplinary framework by Lang et al. (2012). As the recommendations are mainly based on one transdisciplinary framework, I do not imply that some of the suggestions may not have been included in other transdisciplinary or non-transdisciplinary frameworks or actual research in SS. For example, critical research is used in SS to question background assumptions and initial problem formulations (Thorén, 2015); however, it is not included in the framework by Lang et al. (2012). Furthermore, I need to highlight that these results only apply to the theoretical framework of Lang et al. (2012), which limits their applicability to actual transdisciplinary research. The findings from my analysis are split into two categories. The first category concerns improvements that could be integrated in the transdisciplinary framework without limiting its applicability. Also, these suggestions only concern the specific step in which the change is proposed and do not impact the execution of subsequent steps:

- Emphasize the difference between internal and external end-users
- Empathize with external end-users in Phase A to support problem understanding and definition (see arrow from first to second square in Figure 11)
- Use divergent and convergent thinking for problem understanding in Phase A and development of solutions in Phase B
- Reformulate the problem definition – never accept an initial problem definition

The second category of possible improvements for the transdisciplinary framework requires more fundamental changes which could limit its applicability. In other words, the proposed changes could benefit the transdisciplinary framework in some instances, but would possibly render it not feasible for every transdisciplinary research process. The suggestions for improvement in this category concern the interaction between several steps; to be more precise, the iterative connection between the steps:

- Take several problem statements to Phase B to enable more solution options (does not require an iterative process)
- Take several solutions to Phase C and produce prototypes instead of final product
- Iterate the steps of developing solutions and prototyping (see arrow from fourth to third square in Figure 11)
- Produce prototypes instead of final product

- Test prototypes with external end-user
- Iterate the steps of evaluation and solution finding (see arrow from fifth to third square in Figure 11)
- Iterate the steps of evaluation and problem definition (see arrow from fifth to second square in Figure 11)
- Iterate the whole process due to new user-insights gained from prototyping (see arrow from fifth to first square in Figure 11)
- Establish guidelines for iterative cycles in the transdisciplinary framework
- Consider the exclusion of end-users from the research team if their feedback from the steps empathize and evaluation is sufficient
- Iterate the process with the same team members to support a mutual learning process

As seen in Figure 11, nearly all the improvements of my second category are based on iteration after prototyping and the evaluation thereof (see fourth and fifth square in Figure 11).

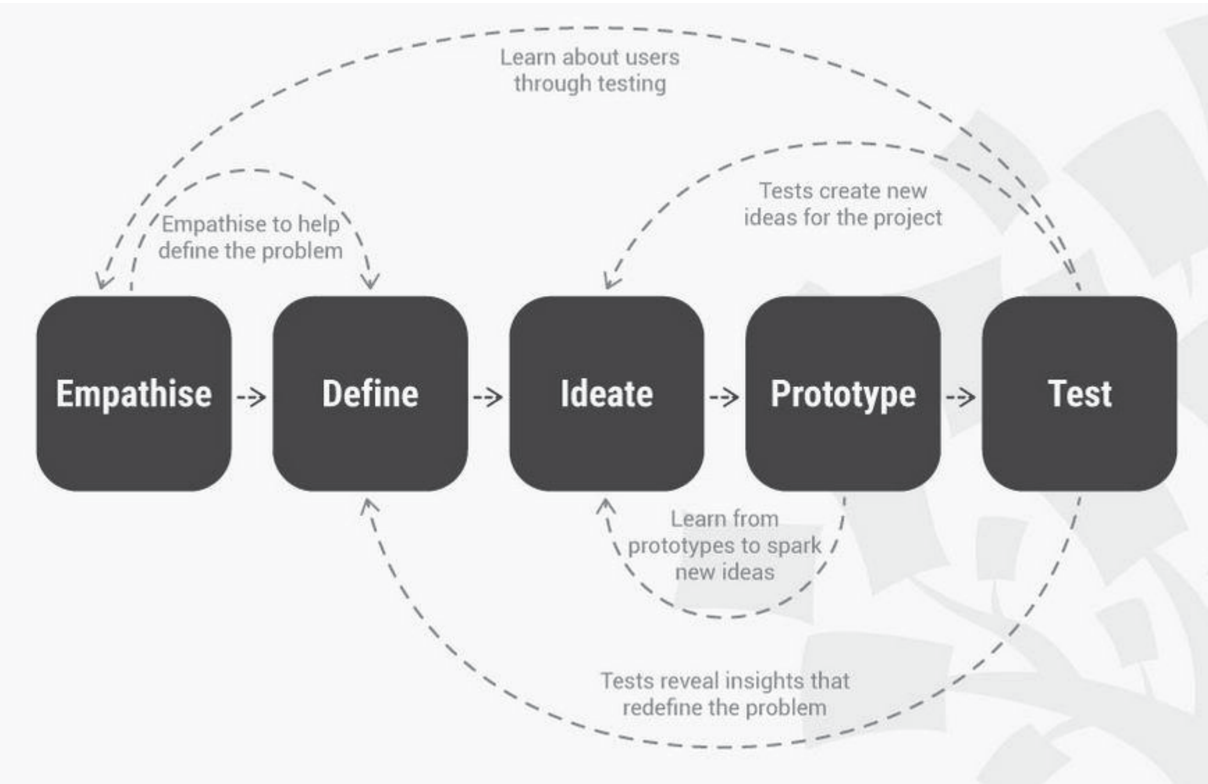


Figure 11. Conceptual framework of the design process including the iterative cycles. Reprinted from (Siang, n.d.)

6 Discussion

The results of my analysis show that DT can support the advancement of the transdisciplinary framework by Lang et al. (2012). I will discuss the benefits and limitations implied in my research results. First, I will discuss the main aspects of how DT can support the advancement of the transdisciplinary research framework.

By empathizing with the user in Phase A, the research team can make sure to formulate and target the most important problems first and increase the quality of outcomes for the end-user. Divergent and convergent thinking should be included in the transdisciplinary framework for increased problem understanding in Phase A and the development of solutions in Phase B. In the transdisciplinary framework, the focus in Phase A and B is only on narrowing down the problem definition to a single research question, then finding solutions to this question. Instead, the framework should emphasize exploration of the problem and solution space. As a result of exploring the problem space, the research team can generate better problem statements and take several of them to Phase B. This gives the researchers the option to explore several solution options. In Phase B, divergent and convergent thinking should be used to create as many solution options as possible and take the best single or multiple solutions to Phase C.

Another finding concerns the difference between the description and visualization of iteration in the transdisciplinary framework by Lang et al. (2012) and DT. Lang et al. (2012) state that their transdisciplinary framework is only described in a linear manner but the steps should be carried out iteratively. Apart from an iterative cycle within Phase A, there are no instructions or signposts of how to implement iteration in the actual research process. This leads to a framework that describes the 'ideal' transdisciplinary research process in a very linear manner and does not convey the message of iterative working between the steps or the entire process. Without looking at the methodologies used and reviewing actual transdisciplinary research, the iteration within a theoretical framework does not directly translate to the iteration within actual transdisciplinary research processes. However limited the implications are, theoretical frameworks build the foundation for actual research, hence their improvement is important. Design Thinking integrates the iterative cycles in a much clearer way, which gives the research team guidelines of where iterative cycles are possible and beneficial. Iterative cycles, such as the ones in Figure 11, could be integrated in the transdisciplinary framework for more clarity.

Apart from the iteration between the first two squares in Figure 11, every iteration is connected to prototyping and the evaluation thereof. Prototypes fulfil two major roles. They feed back into the creative process of developing solutions, and the interaction between users and prototypes feeds back into the empathize step at the beginning of the process. The first point of improvement for the transdisciplinary framework would be to take several possible solution ideas from Phase B to Phase C and prototype them, instead of narrowing the solutions down to a single one. Additionally, developing prototypes instead of final products can help the team to be more creative as it does not have the pressure of delivering a perfect result on the first try (Skogstad & Leifer, 2010). Testing the prototype with external end-users triggers three iterative cycles (see Figure 11). It can help to develop new solutions, redefine the problem and empathize with the end-user. Therefore, the evaluation step has several important outcomes of which the research team is benefitting. Depending on the research project, framework and methodology used, an adaptation of some of the specific iterative cycles used in DT could be beneficial. In comparison to the transdisciplinary framework which evaluates the process after completion (Lang et al., 2012), the evaluation in DT is much more beneficial. This increased value could also lead to a more thorough evaluation by the research team than if the results from the evaluation have no effect on the current process anymore. Design Thinking makes evaluation a part of the process, instead having the step after completion. Highlighting iteration more in the transdisciplinary framework by Lang et al. (2012) could lead to a raised use thereof and stress the potential benefits.

The integration of end-users in the empathize step in Phase A and the evaluation step in Phase C could allow the exclusion of the end-user from the research team. In the analysis, I highlighted several possible issues of including the end-user in the entire process, such as spatial, temporal, and methodological issues. The exclusion could simplify the research process in each of these aspects. However, this implies that prototyping and evaluation are possible. My analysis, results and discussion show that aspects of DT could be integrated in the transdisciplinary framework. Next, I discuss whether the transdisciplinary framework stays applicable to the same sustainability problems after the integration of my suggested improvements.

My main research question concerns the extent to which DT can support the advancement of the transdisciplinary framework by Lang et al. (2012). The integration of aspects of DT in the transdisciplinary framework can lead to limitations regarding many of my suggested improvements. The results in my research are all based on theoretical data analysis of the framework by Lang et al. (2012) and several design thinking frameworks, not real-world research. The main problem in evaluating the applicability of the changed transdisciplinary framework is the variety of sustainability contexts in which it can be applied in practical research. Therefore, I outline several criteria that need to be considered when using the transdisciplinary framework with my suggested improvements. These can also be understood as possible limitations that require further research.

All limitations are connected to the execution of the iterative cycles. Design Thinking is a user-focused approach which heavily relies on the ability to empathize with the user and have the prototype evaluated by the end-user (Skogstad & Leifer, 2010). This requires an identifiable end-user and a solution that can be prototyped, which may not always be given in sustainability problems. The literature on DT suggests that almost everything can be prototyped (Young, 2010). While this may apply to challenges DT has faced so far, it had not been applied in the context of sustainability science yet. One issue of complex or wicked sustainability problems is that the consequences of the solutions can be unforeseeable. Therefore, the effectiveness of prototypes might be limited. For example, when prototyping government policies, the interference by other policies may be not accounted for until the policy is implemented. While prototyping could still be useful to uncover some of these challenges by downsizing the problem (Lindberg et al., 2010), it may reach a limit at some point. If these far-reaching impacts make it difficult to identify an end-user, this would limit the value of prototyping severely. Another problem is the operational timeframe of some projects. For some sustainability problems, the iteration of a single cycle may take years. In these cases, the feasibility of multiple iterative cycles may not be given. Additionally, if the stakes are high and the problem is urgent, the time for multiple iterations may not be given.

Although DT scholars seem too find no limitations for their approach it is important to keep in mind that designers are focused on delivering a solution when completing a project while scientists may conclude with the fact that further research on the topic is needed (Cross, 2006). This may also help to understand the difficulty of a successful transdisciplinary project. While the scientists may be satisfied with producing new knowledge, the practitioners need to be given a tangible product.

Looking at the example of overfishing in international waters reveals several more problems. In such cases, power relations, negotiation, state sovereignty and interest, spatial scales that overlap national boundaries, and unclear or missing legislation are part of the problem. The power relations in a research team have strong implications on the whole process, in terms of initial member selection, problem definition, method selection and the hierarchies in the process. The transdisciplinary process is initiated by scientists (Lang et al., 2012), therefore shifts the power to their side. The DT literature does not provide any reflections on the importance of power structures; although, many of the power related issues highlighted in transdisciplinary research would also apply in DT. The integration of a facilitator educated and experienced in DT could be beneficial for a better balance between scientists and practitioners. However, I cannot judge power related effects of the integration of my suggested improvements. The issue of having to include stakeholder such as sovereign states, and including their interests is another aspect not yet explored by DT. Complex problems, such as overfishing in international waters, incorporate several of the limitations outlined before. The end-user is not easily identifiable; stakeholder selection significantly influences the outcomes and no legal framework is given for the outcomes. In these cases of extreme complexity, DT may not be applicable. However, design thinking has been adapting to many challenges beyond its initial problem field, so it may be able to adapt to more complex sustainability challenges in the future. At this point, I conclude that I am only able to partially answer my main research question. In my research, I highlight points of improvement for the transdisciplinary framework by Lang et al. (2012) but to what extent these improvements limit the process to certain sustainability problems requires further research.

While working on this thesis, the importance of iteration became clear to me thanks to the thorough description of iteration in DT. As the results of my explorative thesis were unknown to me, the framework by Lang et al. (2012) was not picked for its iterative value; therefore, it cannot represent iterativity in SS. However, the lack of clear guidance in terms of working iteratively is an aspect I had experienced throughout my Master Programme *Environmental Studies and Sustainability Science* at Lund University as well. The term *iterative* was used frequently by our educators, and students were told to work iteratively in projects or the employment of frameworks, such as the one by Lang et al. (2012). Working on this thesis has provided me with a clear understanding of the meaning and benefits of working in iterations. Guidelines of iterative cycles could be integrated more clearly and prominently in the transdisciplinary framework used in my thesis. Cupps (2014) argues that the basics of DT should be taught to any student who is going to face complex problems. However, the education of individuals is not enough. Design Thinking only works in environments which support the chaotic and creative way of working which may not result in solutions in the short run but can lead to innovation in the long run (Skogstad & Leifer, 2010). This is because of the nature of DT to keep the results ambiguous to stay flexible and follow unconventional ideas which may result in failures (Tim Brown & Wyatt, 2010).

Following the framework by Lang et al. (2012) and comparing its individual steps to DT was helpful by giving my analysis a clear structure. This structure provided a level of clarity that was beneficial to synthesize my findings into a range of results; therefore, helping me to find answers to my sub-question. However, using only one transdisciplinary framework to compare the DP to has limited aspects regarding the internal validity of my thesis. Now knowing which parts of DT could be relevant for the advancement of transdisciplinary frameworks, DT should be compared to other frameworks which are more representative of the iterativity or practitioner inclusion of transdisciplinary research in SS. Also, the theoretical level of my research makes it difficult to judge if the suggested improvements would hold true in a real-world scenario.

Although the connection between DT and transdisciplinarity in SS was made along the guidelines of a transdisciplinary research framework, I believe that lessons can also be learned for non-transdisciplinary frameworks in SS. Similar to the internal validity of my results, the external validity must still be further researched. However, the possible improvements found and presented in the results section are not specific to transdisciplinary studies. My findings could also apply to multi- or interdisciplinary research teams made up entirely of scientists. For example, the interdisciplinary framework by Jerneck et al. (2011) could make use of the steps of prototyping and evaluation of DT. Design thinking also offers a way to integrate external feedback and insights without having to include additional actors to the team. The same limitations to the integration of my findings apply to non-transdisciplinary frameworks. My thesis is the first research conducted looking at the integration of aspects of DT in SS. As such, it is successful at establishing a connection on which future research can build. Further research will be required to fully understand the implications and applicability of a highly iterative transdisciplinary research framework.

As this thesis is only based on literature and one particular framework, it can only be the first step towards an integration of DT in an actual transdisciplinary research process. Many aspects require further research to confirm my initial findings. To increase the validity of my findings, my research could be repeated using a different transdisciplinary research framework to compare with DT. Apart from more theoretical research, my findings should be tested in the context of an actual transdisciplinary research to establish contexts in which my findings are applicable. A review of transdisciplinary research along the framework of Lang et al. (2012) before and after the inclusion of my suggestions could also help to answer many other questions that I could only partly answer in my theoretical research. The variety of problems SS deals with made it impossible to judge how my proposed changes would alter the research framework. For example, it was not within the scope of my study to find out how the power structures within the research team could change with the inclusion of professional design thinkers. Further research could focus on finding out if including professionals in DT benefits the integration of practitioners in the research. Further research is also needed regarding the development of criteria for the range of application of iterative transdisciplinary research. In other words, which sustainability problems are too complex to be iterated?

7 Conclusion

The best approach SS currently has to deal with sustainability problems is transdisciplinary research. Transdisciplinarity is considered the future of SS (Thorén, 2015), but it is difficult to execute. My aim was to support sustainability scientists in finding solutions for sustainability problems, which I wanted to do by advancing one of the frameworks used in transdisciplinarity in SS. I chose to compare the transdisciplinary research framework by Lang et al. (2012) with DT to identify to what extent differences could lead to a support of the transdisciplinary framework. Furthermore, I wanted to find out how and in which cases DT can support the advancement of the transdisciplinary framework. To answer these questions, I compared the transdisciplinary framework and DT step by step. This structure allowed me to make several findings and suggest improvements for the transdisciplinary research framework.

My results concern the improvement of individual steps and the advancement of the iteration between the steps. The step-specific findings are to empathize with external end-users gain user-insights, use divergent and convergent thinking to increase problem understanding and solution development, and always reformulate initial problem definition. Using DT as an example, the framework by Lang et al. (2012) could improve its iterative guidelines. Design thinking provides clear guidelines for iterative cycles between steps in the process, and of the entire process. The implications of these iterative cycles are manifold. Prototyping products instead of creating final products after the first iteration and evaluation these prototypes with external end-users is at the core of DT. Simple prototypes allow the research team to make their ideas more tangible and spark new ideas. The feedback from prototypes can help to reveal new insights and reframe the problem statement or directly lead to the creation of new solution ideas. The feedback is also used to gain additional user-insight which can feed back into the first step of the research process. Additionally, the fear of failure and retreat to oversimplified or ambiguous solutions can be decreased by having the team prototype instead of developing final products.

Therefore, I argue for a clarity regarding the integration of iterative guidelines in the frameworks by Lang et al. (2012) to increase the iteration of actual research guided by the framework. Design thinking stresses the importance of iterative cycles not only by including it in its guidelines but also by their visual representation of frameworks. However, the possible advancements I found in my research could limit the range of application for the transdisciplinary framework. The variety of sustainability problems prevented me from defining specific criteria for this range of application. Therefore, I could only answer how DT can advance the transdisciplinary framework by Lang et al. (2012) but not to what extent. My thesis establishes a starting point for the integration of DT in transdisciplinary SS research by showing possible improvements. Further research regarding the limitations and applicability in actual research processes are necessary to validate my findings. With more research, transdisciplinary or non-transdisciplinary SS research could benefit from the integration of aspects of DT.

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