Eng Int Syst (2024) 1: 25–33

Engineering
Intelligent Systems

Design Thinking for Sustainable Transformation: An Analysis Framework for Practitioners

Irma Lindt[1,*] **and Wolfgang Gräther**[2,§]

[1]*Cologne Institute for Digital Ecosystems, Technische Hochschule Köln, Gummersbach*
[2]*Computer Science, Hochschule Furtwangen University, Furtwangen*

Design Thinking is an approach to develop innovative solutions for challenging goals and problems with particular considerations of human needs. According to its openness to many problem areas it has a huge number of application possibilities. However, practitioners might not be aware which challenging problem might benefit from design thinking. To support them this paper presents a two-step analysis framework consisting of an identification sheet for design thinking and a method canvas. During the development process our analysis framework has been evaluated in some design challenges and in many workshops on design thinking.

1. INTRODUCTION

For sustainable transformation projects design thinking can be beneficial, since it supports solving challenging problems with creativity and reaching solutions and implementations that really match the sustainability needs identified. The proposed analysis framework could fit the purpose of innovation pathways for practitioners or innovation strategists, guiding them in the identification and specification of sustainable transformation projects. Furthermore, the analysis framework aims at helping practitioners to develop an understanding if and how design thinking could support their problem-solving processes. We believe, the analysis framework can play an important role in the complex interplay of digital ecosystems, sustainable development, and sustainable transformation.

1.1 Problem Solving

The process of problem solving has been researched for a long time and problem-solving strategies have been studied by various scientific disciplines under numerous perspectives [3]. This research has shown that there are significant differences in problem solving in science and technology as well as in design. This is also justified by the characteristics of the different types of problems that are to be solved: design problems often cannot be completely described and are related to so-called wicked problems [20]. However, design has developed practices to deal with these kinds of problems and to develop concrete products, services and systems, which are viable for a certain group of users [9].

Creative engineering is a broad but systematic treatment of design processes, which was developed by John E. Arnold and lectured at MIT, Stanford and in corporations. He considered design processes as problem solving that required creativity and thus corresponding tools to think differently. He states that the creative process involves combining past experience into new patterns that then better solve human needs. His approach is based on a classification of different thinking modes that are related to the corresponding problem types [2]. Overall, creative engineering combines methods of engineering with a human-centered approach and it is a precursor of design thinking [3].

1.2 About Design Thinking

Design Thinking is an approach to creative problem solving that supports the creation of innovative products, services and systems. It focuses on several principles such as a

*E-mail: irma.lindt@th-koeln.de, §E-mail: wolfgang.graether@hfu.eu

human-centric point of view, meaning that solutions to problems must always satisfy human needs. Another principle that has to be followed is that of tangible prototypes that enable discussion of ideas, concepts, specific functions or more complete prototypical solutions at each stage of the problem-solving process. Usually design thinking involves the five steps empathize, define, ideate, prototype and test [17]. These steps are not carried out strictly one after another, because knowledge, for example user feedback, gained in a certain step could require to go back to a previous step. The first two steps could be summarized as exploration of the problem space and the latter three as exploration of the solution space. The iterative alignment of both spaces is key to the effectiveness of design thinking for so-called wicked problems [11] [9] [4].

The design thinking approach became visible and spread after the foundation of the d.school at the Stanford University and the founding of the D-School by Hasso Plattner Institute at the University of Potsdam in 2005 and 2007, respectively. An early and very successful showcase is the development of a baby incubator for less than 100$ [6] that finally resulted in a product sold by the embrace global organization.

A systematic review of design thinking in health care presents twenty-four cases and for each its characteristic, methodology, objective and result. Four studies compared design thinking interventions to traditional interventions and reported greater satisfaction, usability and effectiveness [1]. The characteristics, applicability, tools, methods as well as limitations of design thinking in different educational settings can be found in a systematic literature review [15].

1.3 Relevance for Practitioners

Design thinking is application-independent and thus beneficial for problem-solving and innovation in many application areas such as engineering, information technology, health care or even education. Practitioners should be aware of cases for design thinking in their industrial sector. Many presentations of cases from industry as well as interviews with practitioners are presented in the blog "This is design thinking" [23].

A large-sample survey of design thinking adoption in practice revealed similarities but also differences in the appropriation, use and understanding of design thinking. Themes such as iterative process, problem-solving, user-centeredness and organizing collaboration were frequently mentioned to characterize design thinking, but prototyping was surprisingly rarely mentioned [21]. Note, that the analysis framework relies strongly on tangible prototypes in its identification as well as its method part.

2. RELATED WORK

Typically, frameworks support the mediation of core concepts of theories, methodologies or approaches and they are used to facilitate their application to real-world settings. In addition, frameworks provide users guidance on how to apply the concepts to a specific use case [16]. One example is the workshop planning canvas for design thinking that is presented in [8]. The canvas is paper-based, in landscape format and structured into different parts. The part administration issues remain design thinkers to setup suitable spaces, develop a detailed agenda per day and to invite users as well as participants. There are other parts such as result or feedback for documenting ongoing work. The parts named follow-up, next steps and what needs to be improved drive and support the planning of the design thinking process. According to our understanding the planning canvas is mainly a means for documentation and organization.

In the literature two problem types are distinguished: algorithmic and heuristic [18]. Algorithmic problems are problems with a limited range of solution possibilities and a "known, well established, often sequential and generally predictable" solution path. Heuristic problems are open-ended problems with "a series of choices and decisions made as the problem is being solved". It is suggested that creative problem solving should focus on complex open-ended problems that require a heuristic approach.

The social-ecological systems framework supports the organization and analysis of findings for complex social-ecological systems (SES). Its four related categories (sub-systems) are resource system, resource units, governance system and users. Additionally, there are the categories interactions and outcomes, which are interlinked with these subsystems. All categories are made up of many variables and partly sub-variables that have to be captured. This general framework is used to "identify 10 subsystem variables that affect the likelihood of self-organization in efforts to achieve a sustainable SES" [14].

3. THE ANALYSIS FRAMEWORK

3.1 Identification Sheet

The suitability of design thinking for problem cases is evaluated using the identification sheet. It guides users through the three categories problem type, human needs and tangible prototypes. After exploration and assessment of each category the overall benefit of design thinking for the problem case is assessed qualitatively, see Figure 1.

In the first category, named as problem type, the problem type of the specific problem case is identified, since it serves as good predictive indicator for the benefit of design thinking. There are three classes of problem types analytical, judicial and synthetic [22]. A problem case is of type analytical, if it is quite precisely described with a few concepts and if only one correct (or optimal) solution exists. The solution is achieved through scientific and engineering methods, i.e., logical reasoning using theories, taxonomies, models or other well-defined empirical relations. Analytical problems can often be split into sub-problems, which can be solved more easily.

A problem case is of type judicial, if it has a complex description using many concepts and if there is more than one correct solution. The solution is achieved through elaborating many aspects of the problem under different perspectives. The solution comprises also the judgement and justification for

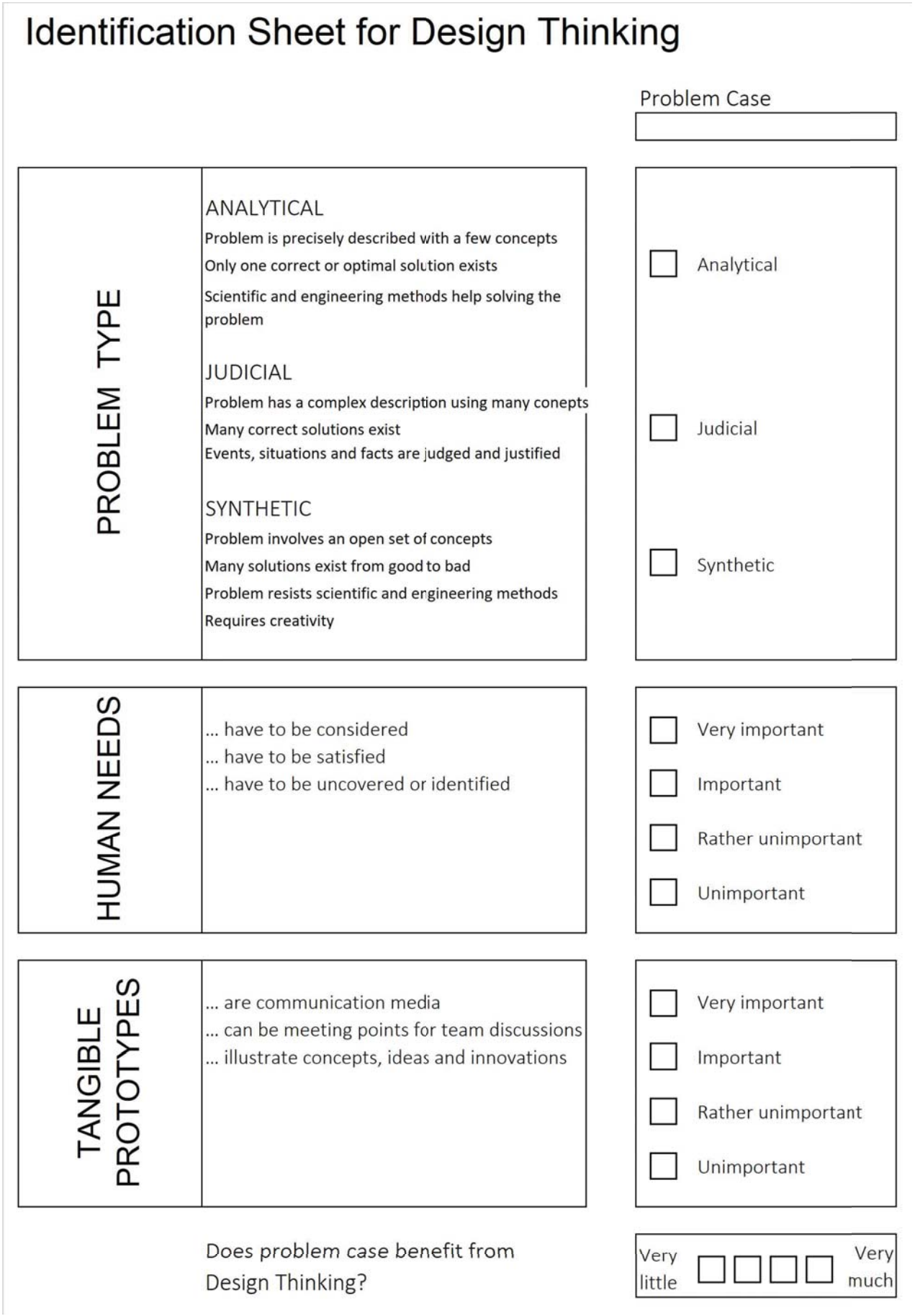

Figure 1 Identification sheet for design thinking.

events, situations or facts based on underlying rules or obeyed laws. Aside from cases in jurisprudence, for example, beauty contests in economy are also of problem type judicial.

A problem case is of type synthetic, if it involves an open set of concepts and if there exist very many solutions, which could range from good to bad. Opposite to analytical problems the solution resists scientific and engineering approaches. Such problems are called "wicked problems" and the solution to synthetic problems requires creativity. Design thinking could be one approach to find solutions that are novel, useful, take into account human needs and satisfy the needs of stakeholders.

The first category describes three distinct problem types and usually only one type will be checked for the problem case at hand. However, if it might look if the problem case combines more than one problem type, then two problem types could be selected. But this situation should then be carefully thought of in the overall rating of the benefit of design thinking.

In the second category, named as human needs, the relevance of a human-centric point of view for a problem case is assessed. Design thinking focuses heavily on the elicitation and consideration of human needs especially during exploration of the problem space. During the exploration of the solution space human needs are captured from feedback to the numerous sketches and prototypes [9]. In this category, the user should evaluate how important consideration and satisfaction of human needs to the problem case are; sometimes it might be necessary to uncover and identify the human needs first. The importance of the human needs is rated on a scale ranging from unimportant to very important.

In the third category, named tangible prototypes, the significance of touchable concepts, ideas or solutions for the problem case is assessed. Prototyping is a central principle of design thinking and prototypes function as communication media in design challenges [11]. Prototypes might help teams to avoid misunderstandings and could serve as an object for storytelling. In the case of digital products, the graphical user interfaces are the tangible parts of the products. In this category, the user should evaluate how important tangible prototypes to the problem case are on a scale ranging from unimportant to very important.

The assessment of the overall benefit of design thinking for a problem case considers the exploration and assessments of all three categories. A problem case benefits from design thinking, if the problem type synthetic is checked and human needs as well as tangible prototype are rated at least as important. The more positively the last two categories are rated, the more beneficial is design thinking for the problem case. Note, if the problem type synthetic is not checked, then the problem case seems to be best solved using the classical problem-solving strategies even if the categories human needs and tangible prototypes are important or very important. The overall benefit of design thinking for the problem case is assessed on a scale ranging from very little to very much. If several problem cases have been assessed, the user can easily find out which one would benefit most of applying the design thinking approach.

3.2 Method Canvas

Once a suitable problem case has been identified using the identification sheet above, the design thinking process is used to develop solutions for the given problem case. While many tools have been proposed for the different design thinking phases [8], we like to share tools that work best according to our experience with teams of practitioners that are not necessarily trained in design thinking.

Figure 2 lists different tools as part of the method canvas. The method canvas shows the five phases of design thinking structured into two parts: the problem and the solution exploration. For each phase, we recommend two tools that work well, but leave also space to add further tools.

In the empathize phase, it is important to get a good understanding of the problem domain, learn about potentially already existing solutions, workarounds and previous research including any empirical studies about the problem case. Furthermore, to develop empathy for who the potential users are and what is important to them, users shall be observed in their environment and open, qualitative interviews can be conducted.

In the define phase, a tool we like to recommend addresses the itches of a problem case, their impact, the available and missing information as well as the involved stakeholder groups and finally, asks you to picture a future where the problem is resolved [7]. Furthermore, a persona, a fictive character that represents the user group, can also be developed in this phase.

Once the problem exploration is completed, you shall be able to rephrase the initial problem into a more refined problem case, before starting the solution exploration.

In the ideate phase, traditional brainstorming following Osborn's rules such as no criticism, encourage wild ideas, go for quantity, and combine and improve ideas can be used [13] [5]. Once a large quantity of ideas is produced, a good way to prioritize the ideas is to get feedback from users. Furthermore, it can be assessed whether the ideas are within the team's area of influence, important enough e.g.. motivate the team to invest a large amount of time to realize them and whether they require new thinking and imagination [7].

In the prototyping phase it is important to assess the user's desirability, technical feasibility and commercial viability of an idea and to define areas that require further investigation. This will inspire the creation of e.g., a paper or screen prototype, that will help further exploring the areas that require further investigation. A comprehensive introduction into prototyping is given by [10]. A more product-oriented prototyping tool is the minimum viable product, where those functionalities of a future product are implemented that help to get validated answers with the least effort [19].

In the test phase it is important to test the solution idea with users. A straight-forward approach is to apply the think aloud protocol [12], where users are asked to articulate their thoughts. Furthermore, in the test phase, the results of the user testing need to be reflected and the important steps for the next iteration has to be decided. We recommend to use another method canvas for the next iteration.

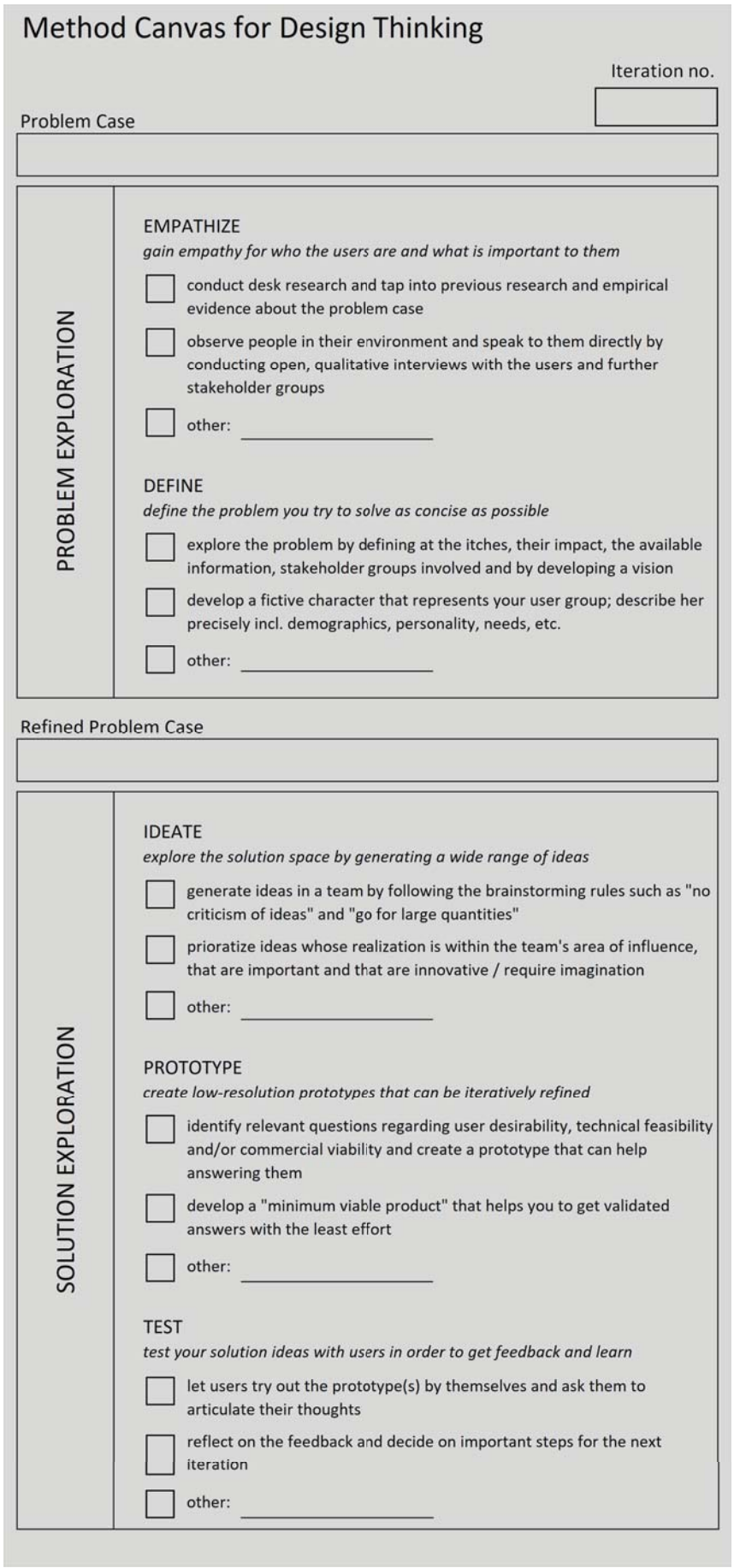

Figure 2 Method canvas listing suitable methods for the different design thinking phases from a practitioners' perspective.

4. APPLYING THE FRAMEWORK

4.1 Three Problem Cases

The first problem case is named *mobility in Furtwangen*. Furtwangen is a regional center in the south Black Forest, where the Furtwangen University (HFU) is located. Students and academic staff form a large part of the population of the Furtwangen area, which is predominantly hilly and partly mountainous. Public transportation is very limited and parking is restricted and in walking distance to HFU very expensive. The goal of this problem case challenges the accessibility of HFU that should be improved and become more sustainable.

The second problem case is named *available space in (small and medium-sized) cities* such as Gummersbach, where the computer science and engineering campus of the Technical University of Cologne (TH Köln) is located. During the Corona pandemic, especially during the lock-down, consumers had realized that it is convenient to shop everyday needs including groceries and other staples online. As a result, a significant part of space in city centers was not utilized any more in the post-pandemic period which led to an economic problem for retail outlets and tenants. This problem hit especially small and medium-sized cities that did already struggle with the decline of their retail sale. The goal of this problem case challenge was to find solutions to make use of the available space within small and medium-sized cities.

The third problem case is named *automatic radio frequency (RF) suspension (during flight)*. One of the authors was involved in a problem case, where a technical solution was needed by a logistics service provider to automatically turn off the transmission signal of a cellular device that was used to track the conditions (i.e. temperature and shock) of cargo during transport with an airplane. The goal of this problem case was to find a functioning solution so that a respective certification could be acquired.

4.2 Applying the Identification Sheet

The presented problem cases will now be assessed one after another to analyze their benefits from using the design thinking approach (see Figure 3). The first problem case, mobility in Furtwangen, is clearly of problem type synthetic, because it involves an open set of concepts and there exist many solutions. The concept mobility is related to other concepts such as pricing, convenience of transportation or individual versus public transport. As solutions one can immediately think of carpools, pedelecs, or even gondola lifts. Therefore, as problem type synthetic is checked. The second category, human needs, is rated as very important, because the problem case requires a strong human-centric perspective and a detailed analysis of the mobility needs. Finally, the category tangible prototypes is assessed. Users – at least in Europe – have experienced many different means of transport and can probably imagine their use, if they are interviewed during the course of the design challenge. Therefore, in this category important and not very important is checked. Note, in this challenge paper prototypes were used to simulate renting and using pedelecs, to examine distribution of pedelecs in Furtwangen. In conclusion, this problem case does benefit very much of design thinking.

The second problem case, available space in small and medium-sized cities, is as well of problem type synthetic, since there are many possible solutions how the space could be utilized and there are other concepts such as renting, shopping, pricing, leisure activities and how one spends her time at work that are related. One can immediately think of many possible solutions. Human needs, although not explicitly stated in the problem case description, play an important role as well, since a solution is needed that is desired so that it will finally be adopted by the users. Depending on the solution ideas and the experience of the users, tangible prototypes might be quite important to get early feedback from the potential users.

The third problem case, automatic radio frequency suspension during flight, is of type analytical, since the problem can be clearly described and only a limited number of technical solutions that automatically detect when cargo is within an airplane and switch off the radio signal might exist. Human needs are unimportant, since the focus is on finding a functioning technical solution. A technical prototype might be important to test and demonstrate the technical feasibility, however, a tangible prototype is rather unimportant, since it won't be used to gather user feedback.

4.3 Applying the Method Canvas

The assessment of all three problem cases with the identification sheet showed that two of them will benefit from design thinking and that for the third problem case, automatic radio frequency suspension during flight, design thinking will not be advantageous. Therefore, the methods for the problem cases mobility in Furtwangen and automatic radio frequency suspension during flight will be further specified employing the method canvas.

Figure 4 shows the method canvas filled for the two selected problem cases. Although completely filled in the figure, the method canvas should in practice be filled in two or more steps. In the first step, only the planning of the problem exploration steps is done. In the second step, once the problem exploration is completed, the planning of the solution exploration steps should start. Our experience shows, that especially in the solution exploration, it is beneficial to plan the design thinking steps one after another.

For the two problem cases we propose to use the following tools. For Mobility on Furtwangen, we suggest to conduct desk research and to speak to people – stakeholders and potential users – in their environments, e.g., at the university, in the city, on parking lots or at bus stops. Since in this case, the problem and its objectives are already well understood, we propose to develop one or a small number of fictive persons (personas) and omit looking at the itches, their impact etc. again in detail. The personas should reflect learnings gained in the empathize phase before. For the problem case available space in cities, we propose to interview people in the city centers and to gain also information from online shoppers, e.g., by conducting online surveys. Furthermore, exploring

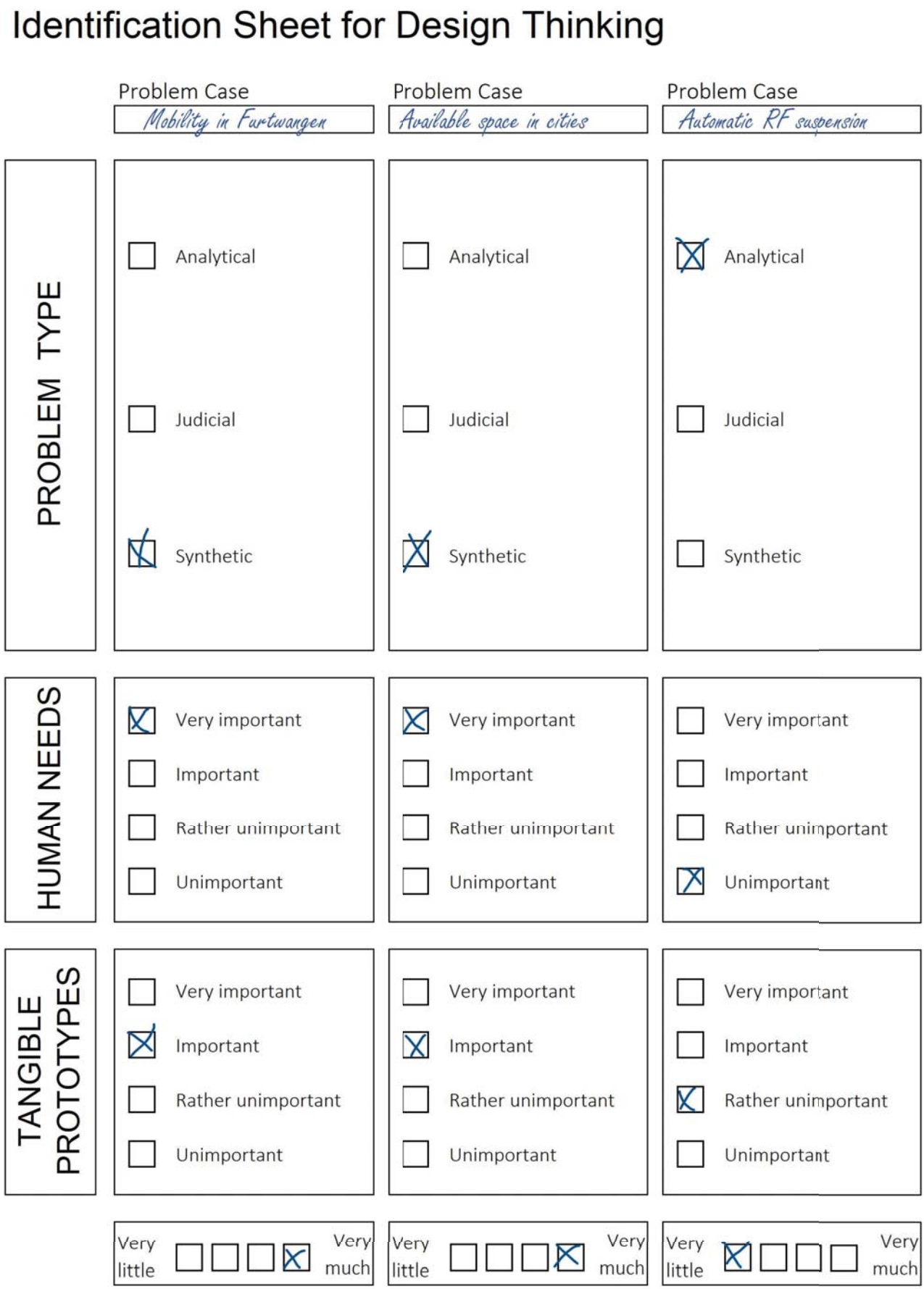

Figure 3 Identification sheet for design thinking filled with three problem cases.

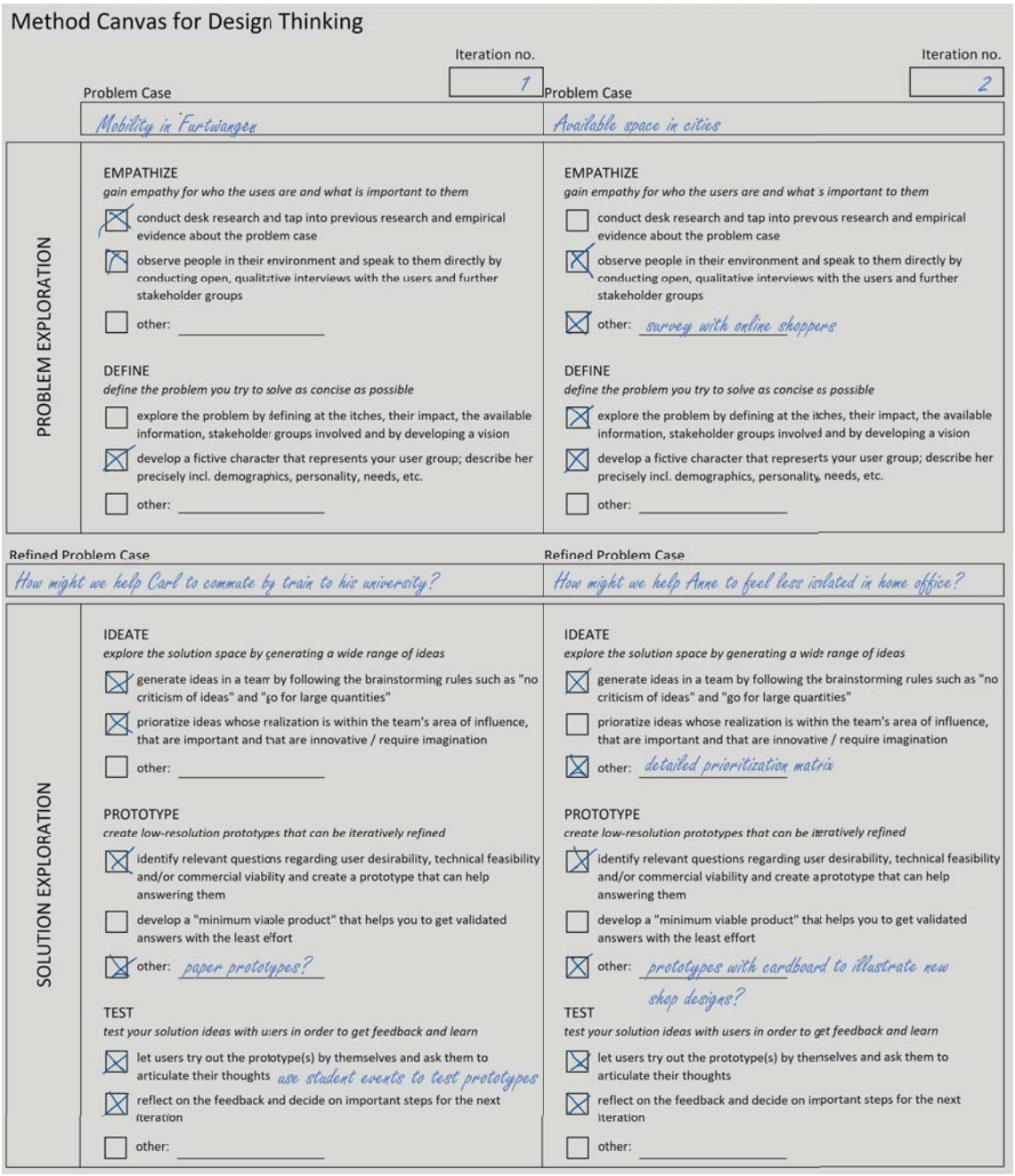

Figure 4 Method canvas for design thinking filled with two problem cases.

the problem in detail as well as developing personas should be done for this problem case.

Once the problem exploration has been completed, the problem case can be refined with the learnings reached so far. As it is typically done in design thinking, problem cases should start with "how might we" and should contain the persona developed in the problem exploration. For the two problem cases, in the prototype phase, relevant questions regarding the user desirability, the technical feasibility and/or the commercial viability should be identified.

For mobility in Furtwangen, paper prototyping and for available space in cities, prototyping with cardboard to illustrate new shop designs could be used as suitable tools. In the test phase we propose for both problem cases to let potential users to try out and provide feedback on the tangible prototypes. Furthermore, reflection on the feedback and the steps for the next iteration should be planned.

5. DISCUSSION AND CONCLUSION

The proposed analysis framework can be compared with the related work presented in section 2 and thereby be located in the research area. A comparison with the workshop planning canvas for design thinking seems especially interesting, because both support users in the application of the design thinking approach. The workshop planning canvas does not support the identification of problem cases as the identification sheet does and it is therefore used only for already identified problem cases. The main focus of the workshop planning

canvas lies in documenting and tracking of the design thinking process. In contrast, the method canvas guides and helps users with tool selection for each of the five phases of design thinking. In sum, the analysis framework provides stronger content support for design thinking processes.

The distinction of the two problem types, algorithmic and heuristic [18], by Puccio et al., can be mapped to the problem types analytical and synthetic used in the problem case identification sheet. While the work from Puccio et al. helps identifying suitable problem cases for creative problem solving, it does not specifically address design thinking and the design thinking-specific aspects human needs and tangible prototypes as it is done in the problem case identification sheet of the analysis framework. The social-ecological systems framework is a multilevel classificatory framework that facilitates understanding of complex social-ecological systems through empirical observations. It could be used to estimate the chances to achieve sustainable social-ecological systems using self-organization. In contrast, the proposed analysis framework is assessment-oriented to identify suitable problem cases and then to select suitable tools to work on the problem case. It also supports documentation and thus comparison of design thinking processes.

In the development of the analysis framework, we focused on an important, but incomplete set of characteristics and tools of design thinking. For example, important aspects of design thinking such as heterogeneity of the team as well as open, flexible rooms were not considered in the problem case identification sheet. Furthermore, compared to other work, the method canvas lists only a small number of tools. Also, we did not discuss the experience level needed to use the analysis framework. However, this rigorous selection of aspects and tools was done on purpose, to simplify the identification of suitable problem cases and to help practitioners to use design thinking in their industry domain. We believe that you need to employ design thinking in order to learn it. Or to put it into other words: the faster you start using design thinking, the faster you learn it. From our point of view, the analysis framework presented in this paper can help practitioners and teams to quickly start using design thinking and can be beneficial for different design thinking experience levels. Printed on paper, the problem case identification sheet and the method canvas facilitate a focused discussion in design thinking teams.

ACKNOWLEDGEMENTS

We would like to thank our industry partners as well as students and academic staff of HFU and TH Köln for their participation and their valuable feedback in the design thinking workshops. In addition, we would like to thank the reviewers for their excellent comments and suggestions.

REFERENCES

1. M. Altman, T. T. K. Huang, and J. Y. Breland, "Design Thinking in Health Care," Preventing chronic disease 15, 2018.
2. J. E. Arnold, (1959/2016) "Creative engineering," in Creative engineering: Promoting innovation by thinking differently, W. J. Clancey, Ed. Stanford Digital Repository, pp. 59–150, 1959/2016.
3. J. Auernhammer, B. Roth, "The origin and evolution of Stanford University's design thinking: From product design to design thinking in innovation management," J Prod Innov Manag., vol. 38, pp. 623–644, 2021.
4. T. Brown, "Design thinking," Harvard Business Review, vol. 86(6), pp. 84–92, 2008.
5. C. H. Clark, "Brainstorming: The dynamic new way to create successful ideas", Garden City, N.Y., 1958.
6. EG, http://embraceglobal.org Accessed July 10, 2023.
7. T. Hurson, "Think Better: An Innovator's Guide to Productive Thinking", McGraw-Hill, 2010.
8. M. Lewrick, P. Link and L. Leifer, "The Design Thinking Toolbox: A Guide to Mastering the Most Popular and Valuable Innovation Methods", John Wiley & Sons, 2020.
9. T. Lindberg, C. Meinel and R. Wagner, "Design Thinking: A Fruitful Concept for IT Development?," in Design Thinking: understand–improve–apply, H. Plattner, C. Meinel and L. Leifer, Eds. Springer-Verlag Berlin Heidelberg, pp. 3–18, 2011.
10. K. McElroy, "Prototyping for Designers: Developing the Best Digital and Physical Products", O'Reilly UK Ltd., 2017.
11. C. Meinel and L. Leifer, "Design Thinking Research," in Design Thinking: understand–improve–apply, H. Plattner, C. Meinel and L. Leifer, Eds. Springer-Verlag Berlin Heidelberg, pp. xiii–xxi, 2011.
12. J. Nielsen, Estimating the number of subjects needed for a thinking aloud test, International Journal of Human-Computer Studies, 41, 385–397, 1994.
13. A. Osborn, Applied imagination: Principles and procedures of creative problem-solving. New York: Charles Scribner's Sons, 1953.
14. E. Ostrom, "A general framework for analyzing sustainability of social-ecological systems," Science, vol. 325, pp. 419–422, 2009.
15. S. Panke, "Design thinking in education: Perspectives, opportunities and challenges," Open Education Studies 1.1, pp. 281–306, 2019.
16. S. Partelow, "What is a framework? Understanding their purpose, value, development and use," Journal of Environmental Studies and Sciences, pp. 1–10, 2023.
17. H. Plattner, C. Meinel, and L. Leifer, eds. Design thinking: understand–improve–apply. Springer Science & Business Media, 2010.
18. G. J. Puccio, B. Klarman, and P. A. Szalay, Creative Problem-Solving. In: Glăveanu, V. P. (eds) The Palgrave Encyclopedia of the Possible. Palgrave Macmillan, Cham, 2022.
19. E. Ries, "The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses", Crown Business, New York, 2011.
20. H. Rittel, M. Webber, Dilemmas in a general theory of planning. Policy Sci 4, 155–169, 1973.
21. J. Schmiedgen, H. Rhinow, E. Köppen, C. Meinel, "Parts without a whole?—The current state of design thinking practice in organizations.," Universitätsverlag Potsdam, 2015.
22. J. P. A. van Thienen, W. J. Clancey, Giovanni E. Corazza and C. Meinel, "Theoretical Foundations of Design Thinking," in Design Thinking Research, H. Plattner, C. Meinel and L. Leifer, Eds. Springer Interantional Publishing AG, 2018, pp. 13–40.
23. TiDT, Blog. http://thisisdesignthinking.net Accessed June 15, 2023.