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EXPLORING BOUNDARY OBJECTS AND THEIR AFFORDANCES IN THE CONTEXT OF DESIGN THINKING PROJECTS FROM A MULTI-STAKEHOLDER PERSPECTIVE

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ABSTRACT

Differences in knowledge backgrounds hinder the work of cross-functional teams by making knowledge integration more difficult, especially when the teams are confronted with novelties in new product development (NDP) projects. Boundary objects are attributed to a mediating capability. While design artifacts are often used to facilitate communication in design thinking (DT) projects, their significance for collaborative problem-solving in cross-functional teams is still unknown. Addressing the gap, we analyze why particular artifacts turn into boundary objects and how these boundary objects can be used in practice to facilitate problem-solving during the NPD process in DT projects. Building on the results of semi-structured interviews with representatives of five DT project teams, we illustrate the insights that boundary objects afford into the practices of stakeholder integration. Our work can help shed new light on the phenomenon, especially concerning the coordinating potential of design artifacts in DT projects. After discussing these insights, we outline directions for future research. We conclude by noting the managerial implications of our findings.

1. INTRODUCTION

Many teams are confronted with situations where their members have not worked together before, represent different fields of knowledge, have to solve complex problems with new task requirements, have fluid team boundaries and temporary membership and have to finish their work quickly due to time pressure (Dougherty, 2001; Edmondson & Nembhard, 2009; Majchrzak et al., 2012; Van Der Vegt & Bunderson, 2005). Especially in the field of new product development (NPD) and innovation, effective collaboration and knowledge sharing in cross-functional teams are considered pressing challenges (Carlile, 2002; Kimble et al., 2010; Wang & Wang, 2012). For instance, authors suggest

challenges in communication due to different viewpoints or knowledge background among involved actors, which in turn may constitute a barrier to innovation (Bechky, 2006; Boland & Tenkasi, 1995; Dougherty, 2001). This is particularly evident in design thinking (DT) projects (Skogstad & Leifer, 2011) due to the multidisciplinary nature of DT teams.

Design thinking is a concept that promises increased innovativeness through a more user-centered approach to innovation (Brown, 2008). Considering that successful DT projects require the involvement of various stakeholders in the innovation process to leverage complementary skills through multidisciplinary teams (e.g., designers, managers, developers) (Mahmoud-Jouini et al., 2016), boundary objects (BOs) play an important role in bridging knowledge domains. The concept of BOs describes an entity (i.e., abstract or physical artifact) that facilitates communication and understanding among different communities of practice by providing a common reference point (Wenger, 2000). While design artifacts are often used to facilitate communication of cross-functional teams in DT projects, research on how and why they turn into boundary objects is still in its infancy (Kernbach & Svetina Nabergoj, 2018). To address that gap, this study aims to analyze why particular artifacts turn into boundary objects and how these boundary objects can be used in practice to facilitate communication in DT projects. This leads to the following two research questions:

RQ1: *How are design artifacts used to facilitate communication between different stakeholder groups in DT projects?*
RQ2: *Why do particular artifacts turn into boundary objects during the DT process?*

To explore the boundary spanning capabilities (how) of design artifacts, semi-structured interviews with representatives of five DT project teams were conducted. The projects aimed at developing digital solutions. Next, to understand why these artifacts turn into boundary objects, eleven semi-structured interviews with participants of the different involved stakeholder groups were conducted. Then, the interviews were analyzed based on the lens of affordance theory (Gibson, 1979; Norman, 2013). Affordance theory analyses a type of relationship between an object and a user, which identifies possibilities that objects offer to humans, taking the abilities and objectives of the user into account (Markus & Silver, 2008; Norman, 2013; Strong et al., 2014).

By applying the concept of boundary objects and affordance theory, this study (i) identifies a set of relevant boundary objects and their spanning capabilities for digital solutions in a DT context, and (ii) analyses affordances that stakeholder groups derive from the identified set of boundary objects. This study is among the first efforts to explore the boundary-spanning capability of design artifacts and their affordance in the context of DT projects. We identify four use practice scenarios that exploit the characteristics of artifacts in the context of DT. Further, we highlight the facilitating and inhibiting factors of the affordance actualization. From a managerial perspective, this study can guide practitioners on how to use boundary objects to facilitate communication and collaboration during new product development in DT projects.

The paper is organized as follows. We start by introducing the research background of design thinking, boundary objects, and affordances in the context of collaborative problem-solving. We then outline the design of the in-depth case study and provide information about the case set-up. After elevating the results, according to the research

goals stated above, we discuss the insights and limitations of our research. We conclude with implications for future research and managerial action, taking that our work offers for understanding collaborative work.

2. THEORETICAL BACKGROUND

In order to investigate the influence of stakeholder perspectives on the boundary spanning capabilities of design artifacts, the DT approach is reflected as a project. The stakeholder groups considered and the associated challenges result from the project structure. The project context determines the following theoretical considerations.

2.1 Understanding Design Thinking

Design thinking (DT) is a human-centered approach that promises to help teams to create desirable products while ensuring technical feasibility and economic viability (Brown, 2008). In doing so, design artifacts are used for augmenting collaborative problem-solving abilities (Goldschmidt & Smolkov, 2006; Larkin & Simon, 1987; Tversky & Suwa, 2009) and facilitating collaboration and co-construction of knowledge (Dove et al., 2018; Eppler, 2004; Sibbet, 2010; van der Lugt, 2005).

Design involves "changing existing situations into preferred ones" (Simon, 1969). In general, DT teams use four principles in design activities (Gaskin & Berente, 2011; Wiesche et al., 2018). First, design is generative in the sense that it involves the creation of novelty (e.g., the "artificial"). To create novelty, design requires the creation of new knowledge or learning in a variety of design-related disciplines (Avital & Te'eni, 2009). Second, design is iterative, as each newly created artifact is subjected to a test, which thus influences subsequent design decisions. The DT teams examine their design hypotheses and subject them to a variety of tests that include requirements, constraints, assumptions, cognitive schemata, or multiple perspectives (Wiesche et al., 2018). The design emerges as a result of the process (Carlgren et al., 2016). Third, these nested generation test cycles occur in conjunction with representations and design artifacts themselves (Wiesche et al., 2018). The DT team investigates alternatives and iterations across representations and learns about both the problem and the solution (Dorst & Cross, 2001). Fourth, design activity is complex because it inevitably and unpredictably leads to unexpected paths (Wiesche et al., 2018). The DT team uses various strategies, including hierarchical decomposition of design (Simon, 1969) or comprehensive description of the design situation (Checkland, 1981), to address these complex design activities. Design thinkers simultaneously construct the problem space while navigating the solution space (Wiesche et al., 2018). Although there are many formulations of design thinking principles, most views are represented in these four principles (Gaskin & Berente, 2011; Simon, 1969). Moreover, there are many DT models in the literature. For instance, the model developed by Uebernickel et al. (2015) depicted in Figure 1.

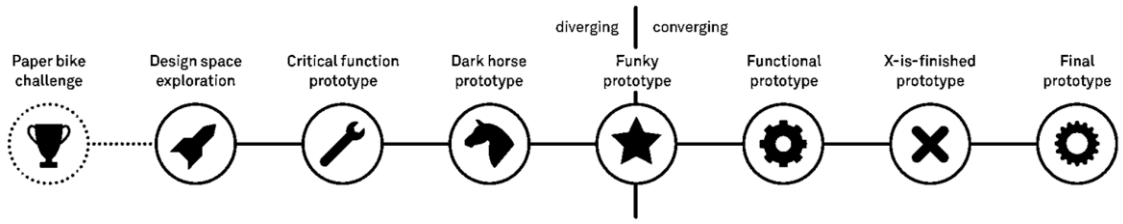

Figure 1: *Marco-process of design thinking (Uebernickel et al., 2015)*

Hereafter, the explanations of the model are based on Wiesche et al. (2018). In the beginning, the DT teams are provided with some basic instructions on the idea of the procedure, the design challenge, and team building activities. In the next step, the teams perform need finding and explore the design space. This is an ongoing phase in which the teams collect, synthesize, and use available information about their design challenges. Next, critical functions are extracted from the problem area that needs to be integrated into the final solution. The dark horse phase explicitly shifts the solution search outside of what can normally be considered reasonable. As a result, the DT teams often encountered successful solutions that were previously considered too "crazy" to use or implement. In the funky phase, the most successful parts of the previous phases are connected, and low-resolution prototypes are built (Wiesche et al., 2018).

The functional phase includes the first concrete preview of the ultimate solution that integrates working functions. During the X-is finished phase, a key functionality – the "X" – is fully implemented and tested. This functionality should consider the core of the ultimate prototype. The final prototype phase includes the solution to one or more important identified requirements and provides the experience of using the real product (Wiesche et al., 2018). Within these phases, an iterative cycle of five steps is continuously iterated (Hehn et al., 2018; Vetterli et al., 2016). The (current) definition of the problem is followed by the discovery of unarticulated user needs, which then influence the brainstorming process to develop new ideas. Prototyping and testing of these ideas make it possible to learn to what extent the targeted requirements have been met, which allows a new, more precise problem definition that restarts the cycle. The DT methodology offers a variety of different elements that can be used at each step of the process (Wiesche et al., 2018).

Reflecting DT as a project, challenges are threefold. First, DT, as a creative project requires people from different backgrounds with different functions and distinct thought-worlds (Dougherty, 1992). Considering the diversity of all stakeholders involved, efficient and effective communication and knowledge exchange is a concern (Eppler & Kernbach, 2016; Graff & Clark, 2019; Häger et al., 2015). The formation of a consistent perception of the domain, requirements, project goals, individual team roles, and the design process itself is challenging. Especially the creation of a common understanding is an ongoing process that is built and rebuilt through the interaction of team members (Clark & Brennan, 1991).

Second, DT, as a project, does not exist on its own. Providing the resources, the project is carried by one or more organizations and has more or less clear boundaries with its stakeholders. This results in integration or handover challenges (Beyhl et al., 2013; Häger et al., 2015). On the one hand, design artifacts have to be transferred to internal or external customers. On the other hand, idea generation is often separated from the implementation (Beyhl et al., 2014). Third, DT, as a creative project, is a time-limited endeavor. Especially after the end of the project but not only afterward, the emergent nature poses a challenge for traceability (Gotel & Finkelstein, 1997). Tracking the project path proves to be difficult (von Thienen et al., 2015). Much knowledge is not documented at all and remains implicit, which poses the risk of information loss during the process (Hehn et al., 2018). This conflicts with the need for transparency – all stakeholders understand what is being done and how certain ideas were generated (Häger et al., 2015).

2.2 Boundary Objects

Knowledge sharing across boundaries is challenging in NPD and significant within DT project teams. Particular problems in communication arise due to different viewpoints or knowledge backgrounds among involved actors, which in turn may constitute a barrier to innovation (Skogstad & Leifer, 2011). Design artifacts can take on a common reference point during the course of DT projects and turn into boundary objects (BOs). In this sense, BOs enable "representing, learning about, and transforming knowledge to resolve the consequences that exist at a given boundary" (Carlile, 2002, p. 422).

In the mediation and translation of social and conceptional worlds, Carlile (2002) identifies three different types of knowledge boundaries. First, the syntactic boundary refers to a lack of common syntax between different stakeholder groups and the resulting language differences (Carlile, 2002). E.g., to express novel ideas, designers or managers may have to develop a new vocabulary that is difficult to communicate to developers. Second, the semantic boundary refers to differences in interpretation between different stakeholder groups (Carlile, 2002). E.g., designers and developers often have inconsistent interpretations of the desired product qualities. Third, the pragmatic boundary refers to different viewpoints of stakeholders rooted in different interests (Carlile, 2002). E.g., managers and technical experts may have different views on how to implement a function, as the managers are interested in low development costs, and developers are interested in technical elegance.

BOs are defined by their capability to serve as bridges between overlapping social and conceptual worlds (Dougherty, 1992). Anchored in these worlds and thus meaningful, they create the conditions for collaboration, while their flexibility of interpretation means that they do not require "deep sharing" (Nicolini et al., 2012, p. 614). This is based on the understanding that the boundary spanning capabilities of an object relates to its properties. In particular, an object is abstract when it represents ideas in ambiguous, rudimentary or generic terms, but is concrete when it represents ideas in unambiguous or specific terms. An object is plastic if it can be adapted to situational requirements, and an object is robust if it cannot be adapted to situational requirements (Star, 2010).

While early research focused on objects and their properties (Carlile, 2002, 2004), other studies draw attention to what people do with objects, i.e., practices (Levina & Vaast, 2005; Nicolini et al., 2012). The latter studies show that objects only unfold their boundary spanning capabilities if they are meaningfully incorporated into working practices. Therefore, objects do not automatically enable the transfer, translation or creation of knowledge. They have to be appropriated to the situation of the actors (Levina & Vaast, 2005). In addition, according to Huber et al. (2020), the usage of BOs can have various desirable effects. For example, objects can facilitate the transfer and translation of knowledge (Carlile, 2004), the balancing of interests (Levina & Vaast, 2005), the coordination of expertise (Barrett & Oborn, 2010) and the overcoming of cultural differences (Barrett & Oborn, 2010), the realization of a vision (Boland et al., 2007), the communication of design ideas (Boland et al., 2007) and joint problem solving (Ewenstein & Whyte, 2009).

Doolin and McLeod (2012) argue Star's (2010) revised conceptualization of BOs objects is compatible with the ontological foundations of socio-materiality and they reformulate the use of design artifacts as a socio-material practice. In line with Huber et al. (2020), two implications of their work are particularly relevant for our research. First, object

usage practices are highly context-sensitive, i.e., "a [BO] may be performed differently across multiple sites, times, practices and participants, with varying effects" (Doolin & McLeod, 2012, p. 571). This calls for research in novel contexts with unique and even extreme properties to better understand the nature of object usage. Second, the usefulness of a BO in bridging different boundaries of knowledge is neither completely determined by its material properties nor by the intentions of the people who use the object but results from the "constitutive interweaving of the two" (Doolin & McLeod, 2012, p. 573). This requires research that explicitly recognizes two roles of object properties, i.e., how different object properties afford different usage practices and how these usage practices in turn form object properties (Doolin & McLeod, 2012). DT, with its pronounced penchant for the visual and material, offers the unique opportunity to answer these calls by providing new context-specific explanations. In the sections that follow, then we mobilize the theoretical lens of affordances in order to develop new insights into the role that design artifacts perform in the interplay stated above.

2.3 Affordances

Anchored in the objective to explore what boundary objects afford knowledge mediation and translation between DT stakeholder groups, we ground our research in the theory of affordances. Originated in ecological psychology, it traces back to the logic that animals recognize the possibilities that objects in their environment offer to them (Gibson, 1977). As widely adopted in different domains (Hartson, 2003; Kreijns et al., 2004; Seidel et al., 2013), we build on the concept of functional affordances, i.e., possibilities for goal-oriented action afforded to specified stakeholder groups by objects (Markus & Silver, 2008). Therefore, this relational concept has to be seen in the context of (1) a stakeholder with his capabilities and goals and (2) the material properties (e.g., characteristics) that the design artifact provides. Herein, functional affordances are objective, i.e., they exist without being perceived and valued by a stakeholder in terms of meaning and interpretation, and they are subjective, as a specified stakeholder group is required “as a frame of reference” (Pozzi et al., 2014).

There are two main reasons why this theoretical lens is particularly well suited for this exploratory research. First, taking up an affordance perspective allows us to investigate the following: (1) the causal potentials of design artifacts and (2) the goals, motivations, characteristics, and abilities of the stakeholders considered. Second, the relational character of affordances is fruitful to shed light on the conditions under which the creation, perception, and actualization of affordances takes place for different stakeholder groups. This in line with the socio-materiality perspective on BOs – reciprocal relationship of object properties and use practices (Leonardi, 2011). Affordances are real, in case they exist independently of the perception of the stakeholder (Gibson, 1977).

Previous research distinguishes between the emergence of action potentials (i.e., the existence of an affordance for a particular stakeholder), their recognition (i.e., the perception by the stakeholder) and their realization (i.e., the actualization by the stakeholder, which can lead to certain effects) (Bernhard et al., 2013). The existing possibilities for action that a design artifact offers certain stakeholders are neither infinite nor always possible (Strong et al., 2014). In fact, depending on their abilities and goals, the possibilities offered may be limited to certain stakeholder groups (Strong et al., 2014). Stöckli et al. (2019) link the emergence, perception, and actualization of affordances to

the socio-material conditions. The decomposition into social (i.e., actors and structures) and material (i.e., artifact characteristics and use practices) subsystems allow us to understand why design artifacts become BOs for different stakeholder groups and why not.

The archetypes of perceived functional performance can be distinguished in two dimensions (Savoli & Barki, 2013). First, perception changes with the goals and wishes of the stakeholder under consideration. Secondly, stakeholders can perceive themselves or artifacts as actors. The perception of value is influenced by many factors (e.g., available information) and includes the perception of non-existent value (Bernhard et al., 2013). Perceived affordances can be actualized depending on the stakeholders' agency and influenced by factors such as the expected result or the perceived effort (Bernhard et al., 2013). For a particular stakeholder, a particular design artifact can provide several affordances. These affordances may be interdependent. The affordances may also be considered at different levels, namely at different stakeholder group levels (Leonardi, 2012; Strong et al., 2014) (e.g., individual, group, organization) and from different design artifact perspectives (Savoli & Barki, 2013) (e.g., conceptual or physical).

The empirical study, next, demonstrates how design artifacts turn into BOs. The affordance lens can produce a level of understanding about the role of objects in collaboration that the concept of BOs could not achieve when used in isolation. The novel insights that derive from this juxtaposition of approaches make up the final part of the paper, together with signposts for further research.

3. RESEARCH METHODOLOGY

Building on the conceptual foundations pointed out before, this study aims to analyze how design artifacts in DT projects turn into BOs and why. Striving to contribute towards a better understanding of the boundary-spanning capabilities of design artifacts, we inductively gain rich empirical data (Corbin & Strauss, 1990; Eisenhardt, 1989) from an embedded multiple-case study to investigate the phenomenon of interest in its real-world context (Yin, 2003). The cases derive from a university course where teams face a design challenge provided by a corporate sponsor. Since we aimed to achieve generalizable and robust results, we selected cases that were mainly replications (Yin, 2012), i.e., projects that took place in the same social structure of the university course.

3.1 Case setting

Five DT projects developed as part of a master's course in a university context were selected. The five DT projects were selected based on the premise of similarity (Eisenhardt, 1989). For instance, project duration (8 months), a digital technology-related problem definition, and a multidisciplinary team configuration (mainly master students from management, design, computer science, and engineering). Each project was composed of the following stakeholder groups (i) design team, (ii) corporate sponsor, (iii) external developer and (iv) teaching team. The design team acted as the primary stakeholder group by being in the center of the relationship and in close contact with all the other stakeholder groups. The interaction among the actors occurred in four distinct modes with respective boundaries. Figure 2 illustrates the boundaries among the mentioned stakeholder groups involved in the design thinking projects.

(1) *Intra–design team*. The design teams consisted of students from two universities. In this study, the design team from the selected university is called “local design team”, whereas the design team from the second university is called “partner design team”. The entire team is referred to as the design team. The local design team met several times a week for personal work sessions. The interaction with the partner design team was based on a weekly conference call. Depending on the geographical distance, several real working meetings took place during the course of the project. The design teams had little or no experience in using DT to create design artifacts. However, they shared the same level of coaching support from the teaching team who are experienced DT experts to identify needs and artifacts to address their problem.
(2) *Design team – corporate sponsor*. Every design team had a liaison with a corporate sponsor, comparable to an internal customer relationship. An exchange took place weekly via conference call and every two months personally in a workshop. The corporate sponsor of each team was responsible for indicating the challenge that each team would work on during the eight months of the project. (3) *Design team – external developer*. If certain programming skills were required that were not available within the team, the teams were free to work with one external service provider. (4) *Design team – teaching team*. The teaching team consisted of two professional DT coaches and met weekly with each project team to discuss the current project status and potential next steps. The teaching team is responsible for coaching the design teams. For that, they followed the design thinking approach discussed in Section 2.

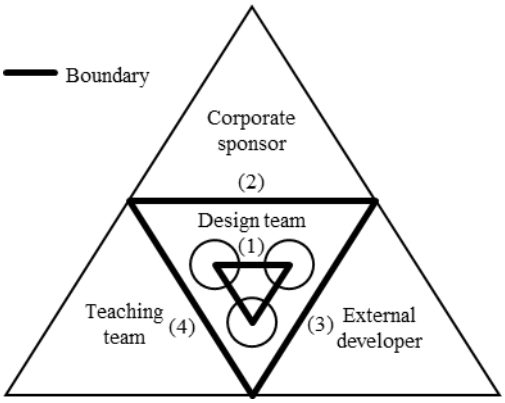

Figure 2: *Boundaries among stakeholder groups involved in a design thinking project*

3.2 Data Collection

To address our research questions, we obtained data from three sources of evidence consisting of course-related documents (SoE1), card sorting (SoE2), and semi-structured interviews (SoE3). In total, eleven semi-structured interviews with five students, four corporate sponsors, and two teaching assistants were conducted in the timespan of March and April 2019. All interviews were recorded and transcribed right after conduction. To further disclose the interview process, all interviews were conducted either in German or English, depending on the native tongue of the interviewee to increase the expressiveness of their statements. Due to large distances, all interviews were conducted using online video chat software (i.e., Skype and Zoom). Miro (previously known as RealtimeBoard) was utilized for card sorting as a method for knowledge elicitation (Barrett & Edwards,

1995). Table 1 illustrates how members of the different stakeholder groups are related to the five selected projects, and also the duration of the interviews.

Table 1: *Sources of evidence according to stakeholder groups*

Stakeholder group	Interview	Embedded case (project)	Duration
(1) Design team	#01 #02 #03 #04 #05	A B C D E	1:07:52 h 1:29:23 h 1:08:14 h 1:10:34 h 1:24:08 h
(2) Corporate sponsor	#06 #07 #08 #09 n.a.	A B D D E	0:39:39 h 0:33:47 h 0:29:29 h 0:21:06 h n.a.
(3) External developer	n.a. n.a.	C D	n.a n.a
(4) Teaching team	#13 #14	A, C, E B, D, E	0:33:01 h 0:40:14 h

The interviews were composed of two rounds. The first round of interviews aimed at investigating how design artifacts turned into BO during the projects from the design team perspective. In this way, members of the design team sampled purposefully according to their availability and willingness to participate (Spradley, 1979). We started with structured questions to record the personal background of the interviewees. Grounded in open-ended questions, the interviewees were asked to name and describe objects they perceive as boundary spanning. The concept of BOs was described in the natural language of the interviewees as it is rather abstract and thus not intuitively understandable. During the interviews, participants were asked to play a card sorting exercise (SoE2), which consists of pre-labeled cards, each displaying artifacts derived from course-related documents (SoE1). In particular, incorporating card sorting activities into in-depth interviews has proved as a research approach to gain an understanding of how participants understand and organize concepts (Conrad & Tucker, 2019). The participants were then asked to assign all artifacts they consider as BO to the respective stakeholder group, where the object serves as important boundary-spanning means (multiple answers possible). Hereafter, they were asked to select three objects per stakeholder group they considered as most useful in terms of their boundary spanning capability. Finally, these objects were discussed in regard to their affordances. While the concept of affordances itself was not introduced to the participants, they were asked for specific use cases of each object and why they consider it as especially useful. As affordances are mostly perceived unconsciously, participants are likely to have difficulties articulating why they used certain objects and why these objects have been especially useful. Therefore, laddering was applied as an interview technique to elicit information which are otherwise very difficult to obtain (Miles et al., 2014; Reynolds & Gutman, 1988). The interviews lasted between 67 and 89 minutes. The interview guide was discussed within the teaching team and pre-tested in a pilot interview.

The interview guide for the second round of interviews was prepared based on the information gathered during the first round of interviews with the design team. The second round of the interviews aimed at testing the pre-identified BOs (three objects per

stakeholder group) with stakeholders that are not part of the design team. The following modes of interaction were considered (1) design team - corporate sponsor, and (2) design team – teaching team. Only two design teams collaborated with external developers, and these could not be accessed. For that reason, this group was excluded. All interviewees from the second round were asked the same questions as the first group concerning their personal background. Following a detailed introduction of the context and objective of the study, the interviewees were asked regarding their perceived affordances of the three selected BOs. Similarly to the first round of interviews, laddering (Miles et al., 2014; Reynolds & Gutman, 1988) was applied again as an interview technique to elicit in-depth insights on the perceived affordances. After discussing the pre-selected BOs in detail, the participants were asked if and why they consider any other artifact as especially useful in terms of their boundary spanning capability at the interface to the design team. The interviews lasted between 21 and 40 minutes.

3.3 Data Analysis

According to the principles of grounded theory, the analysis of the data started at the same time as the data collection. The analysis is based on the coding of the collected data (Lawrence & Tar, 2013). In order to analyze the collected qualitative data, all recorded interviews were transcribed literally (Corbin & Strauss, 2008). While all transcripts were written in the original language (German or English), the coding is subsequently carried out in English. According to the guidelines of Corbin and Strauss (2008), an open coding technique was performed for this study. During the process of open coding, in which the data is broken down and grouped into codes (Corbin & Strauss, 2008), initial concepts and relevant information regarding perceived affordances were identified. All interviews were coded line by line (Glaser, 1978), using the software NVivo to assist in the coding and analysis of the data.

4. RESULTS

Embedded in five DT projects carried out in a comparable social and organizational context of an university course, our research particularly analyzes design artifacts that turn into BOs concerning four stakeholder boundaries. The boundaries represent the four modes of interaction, as depicted in a triangle in Figure 2. How and why these artifacts turn into BOs is illustrated by providing information about the use practice context. Usage practices refer to how project stakeholders use an object in specific situations (Levina & Vaast, 2005), i.e., in our work, the different activities and actions through which DT project stakeholders interact with design artifacts. The use practices are derived from the Stanford Design Thinking process, as described in Section 2. Based on the card sorting results, only artifacts that have been attributed boundary spanning capabilities by at least four design team members are considered. These artifacts include stakeholder maps, personas, sketches and scribbles, feedback grids, low-fidelity prototypes, high-fidelity prototypes, and final documentation. Further artifacts are highlighted in the DT use practice context.

4.1 Boundary objects and their spanning capabilities

In line with Huber et al. (2020), our conceptualization of the design artifact as BO adopts the broader concept of artifacts in a DT environment and recognizes the ubiquity

of artifacts in this context: The artifact is not a single object, but a multitude of simultaneously existing, related objects (Nicolini et al., 2012). Due to their social materiality, design artifacts are open for a wide variety of interactions. In this study, however, we identified common use practices in the context of DT projects in an educational setup in the form of use scenarios that explain how design artifacts turn into BOs. According to the criteria of Star (2010), on a superordinate level, four patterns of use practices were identified. The interrelation, which we have adapted to the context of DT and illustrated in the form of a matrix, is shown in Figure 3. Here the boundaries are to be understood as fluid. More specifically, the identified use practices can be considered (1) to *create knowledge collaboratively*, (2) to *validate knowledge*, (3) to *assess knowledge*, or (4) to *deliver knowledge*.

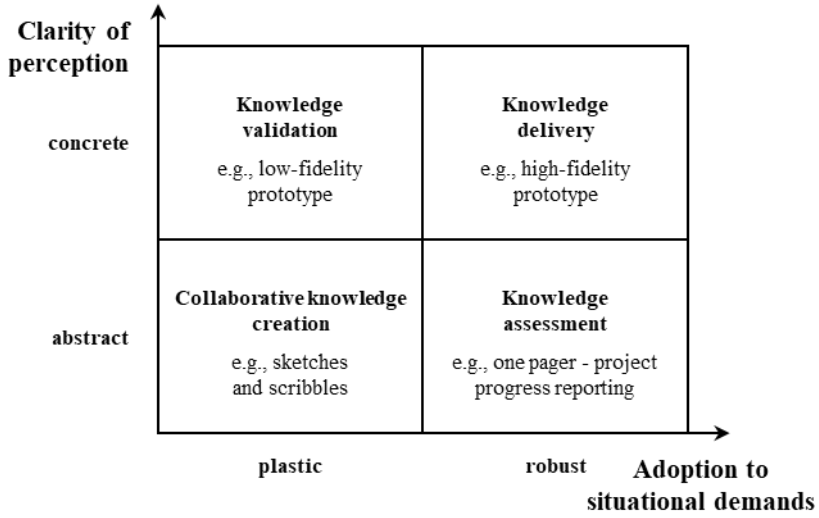

***Figure 3**: Boundary object use scenarios in the field of DT (axis division based on Star, 2010)*

Collaborative knowledge creation. Observations, empathic feelings, and tacit knowledge tend to be chaotic or unstructured (Glen et al., 2015, p. 201). In order to create a community of practice (Lave & Wenger, 1991), it is, therefore, necessary to find ways to extract and visualize the knowledge and to search for themes and patterns. Herein, visualization and sense-making activities are important for organizing, framing, and reframing shared knowledge. In this regard, especially within the design team, sketches, and scribbles are considered particularly valuable (#01, #02, #03, #04). They helped to identify overlapping or divergent ideas (#1), promoted a shared understanding of ideas under discussion (#01, #02), and were reference points for further discussion (#1). As these are abstract and plastic artifacts so that they can be adapted flexibly and dynamically as knowledge develops. Design teams face periods of indeterminacy and equivocality (Welsh & Dehler, 2013). Abstract and plastic artifacts help to deal with the ambiguity as they move from the design challenge through the design space exploration phase. The abstract nature of the artifacts can turn into concreteness as the teams gather more information they can make sense of. The abstractness may not subside until patterns begin to emerge, and promising ideas take form as concrete prototypes (Brown, 2009).

Knowledge validation. While design teams progress through the DT project, they engage in a series of validation cycles (Dorst & Cross, 2001). For instance, the creation of artifacts includes developing low fidelity prototypes to facilitate dialogue with the

stakeholders, observing reactions and interacts with the prototypes, and learning from this process to confirm or invalidate the assumptions underlying the prototype creation, leading to the development of new knowledge (Glen et al., 2015). Especially, artifacts that are concrete and plastic are used to examine and test design hypotheses from different points of view. To a certain extent, they also support knowledge decomposition. In that line, plastic artifacts serve primarily for the internalization of knowledge and to bridge borders between the design team on the one side and corporate sponsor or teaching team on the other side (#01, #02, #03, #04, #05). For example, low fidelity prototypes promoted the insight generation from different knowledge backgrounds (#04). They supported manifestation for feedback (#01, #02, #03, 04, #14). One corporate sponsor stated: “Those things make the work [tangible] because there is a lot of vagueness around what is happening [...] it makes things concrete. That is the big word here" (#08).

Knowledge assessment. Due to the attachment in a project-bearing structure, the design team needs to report about resources used and the progress made. In the context of DT, this can be regarded as internal proof of viability and feasibility. Viability and feasibility must be formally addressed and subjected to feedback (Glen et al., 2015). This involves the movement from understanding “what wows” to understanding “what works” (Liedtka & Ogilvie, 2011, p. 21). Given the formal context, the artifacts used for this purpose are robust but still rather abstract. These artifacts make fewer assumptions about the ability to predict the final outcome, allowing for flexible experimentation, assumption testing, and reduced cost of failure. In earlier phases, communication had included gathering information from outside of the team, intense interaction within the team, and soliciting feedback. In the final phase, the design teams demonstrate the ability to confidently present their decisions regarding business viability (Glen et al., 2015). Especially one-pagers were mentioned here to make knowledge accessible for the corporate sponsor and teaching team (#01, #02, #03, #04, #05). The one-pager supported the communication of key activities and learnings for every phase (#01, #06). As they were "short, straight to the point, and simple to read" (#14) and exchanged on a regular basis, the design team thought it is more useful to share the project process with the corporate sponsor than the documentations submitted in the middle and at the end of the project (#01). Further, the corporate sponsors valued one-pagers' ability to have something they can share with third-parties not involved in the project (#01, #09).

Knowledge delivery. At the end of the project, the knowledge must be made usable so that it can be processed without further explanation. Artifacts that are concrete and robust can be used directly by the recipient for knowledge consumption, as far as the artifacts themselves allow it. The knowledge is made available to the recipient in an easily processable way. In the context of the educational multi-stakeholder setup, especially high-fidelity prototypes and final documentation were assigned to this class of artifacts. They are handed over to the corporate sponsor and teaching team in the final phase of the project (#01, #02, #03, #04, #05). The “external” stakeholder can only use the functionalities that are given to them directly and perceive additional information provided by the final documentation. The interviews pointed out the documentation enabled them to communicate the whole project journey (#02, #06, #07) and reasoning behind the final solution in an amount of detail they were not able before (#01, #04, #13). Moreover, the corporate sponsors perceived the final documentation not only valuable in the context of the project but also as means to leverage learnings for subsequent projects

(#06, #07). In addition, the final prototype promoted the "imaginative power [of] how [the] final product could look like" (#09). To conclude, artifacts become BO if their characteristics match the needs or objectives of the stakeholders. The relationship is further explored under the lens of affordances.

4.2 Affordances according to stakeholder groups

Interpreting design artifacts through the lens of affordances reveals further characteristics of their boundary spanning capability. Boundary objects entail forms of physical and social materiality, which are relevant to stakeholders and endure across time and place (Leonardi, 2012). However, to obtain meaning and effects from boundary objects requires their enrollment in practices embedded in the social structure of the projects (Orlikowski & Barley, 2001). To understand why artifacts, develop boundary spanning capabilities between different stakeholders, the analysis of affordance provides a revealing approach. Defined as the possibilities for goal-oriented action provided by an object (Markus & Silver, 2008), a closer examination of the perceived affordances can shield light on the motives of the stakeholders. For this paper, the final documentation is analyzed. Our research reveals affordances and constraints in the context of DT projects. In the following, these affordances and constraints are explained by providing empirical evidence from the actualization context. It is in the nature of affordances that design artifacts offer different opportunities to different people. Since the final documentation is only relevant for the stakeholder design team, corporate sponsor, and teaching team, the elaboration will be limited to them.

Perceived boundary spanning capabilities. First, the final documentation is used for capturing experiences and sharing with third parties that have not been directly involved (#02, #04, #06, #07). Furthermore, the final documentation is utilized for communicating the reasoning behind decisions taken during the course of the project (#2, #4). In particular, boundary-spanning capabilities were perceived by exchanging a number of details that could not be shared before. Aside from attracting attention to the project (#04), the final documentation is used as a reference point to look up learnings made during the project (#06, #07). Second, boundary-spanning capabilities include manifestation for feedback (#07). For instance, based on the documentation, the corporate sponsor and the teaching team had the opportunity to ask questions about the general course of the project and the final prototype. Third, the final documentation is used for gaining a holistic overview (#01, #13) and a basis to evaluate the projects' quality. Lastly, it was used to dispel doubts among corporate project sponsors (#02).

Constrains. First, constraints emerged from the information complexity of the final documentation. The stakeholders perceived high media processing efforts compared to artifacts of lower information density such as one-pagers, while the richness of usable information was limited for some stakeholders. One design team member even doubted the final documentation "is just too comprehensive to be actually read" (#01). Second, the design teams faced constraints from the limited perception of use cases of the final documentation. They did not consider the affordance that the corporate sponsors could make use of the documentation also after the project is finished (#02, #04). Third, the design team members perceived constraints in one-time unidirectional communication. They perceived exchange on a regular basis (e.g., via one-pager) more useful than submitting documentations in the middle and at the end of the project (#01). Fourth,

design team members and corporate sponsors perceived constraints due to its mediating nature. They highlighted the essential role of personal communication and interaction to encourage close collaboration (#05, #06, #07). Company visits and other face-to-face meetings are perceived as very important from both.
Still, stakeholders may or may not realize the perceived boundary spanning capabilities. In fact, the perceived value decreased according to the level of involvement. Our results suggest that understanding an individual's boundary-spanning actualization requires the socialmatrial context (Leonardi, 2012), which compromises facilitating (+) and impeding (-) factors. Figure 4 summarizes the factors according to the artifact and social subsystem.

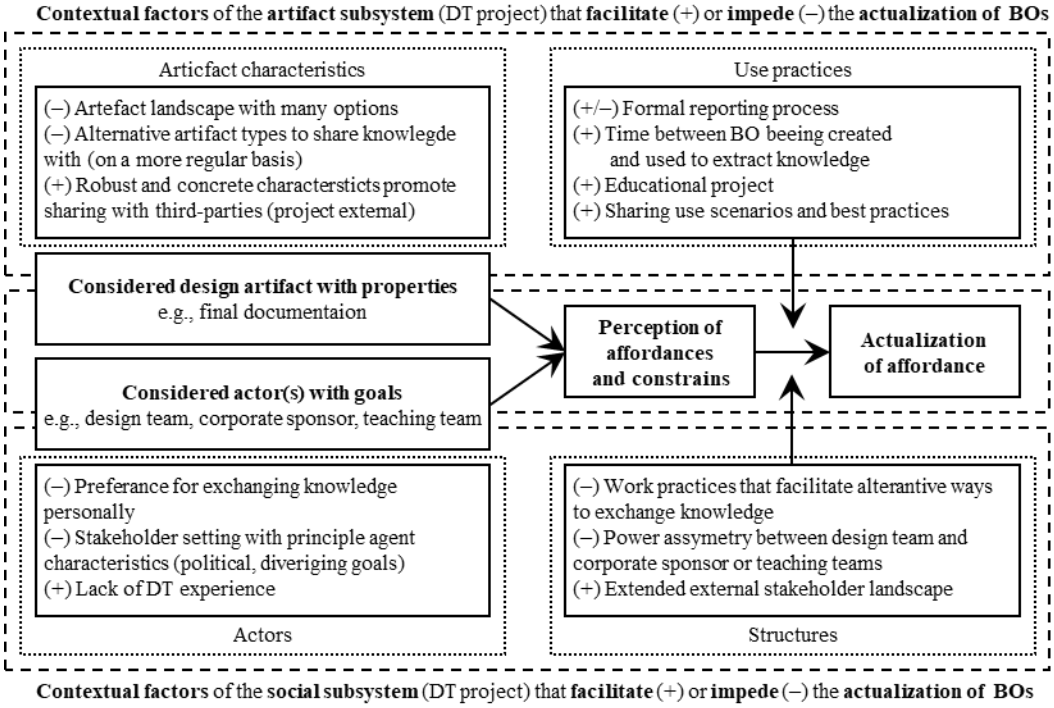

Figure 4: *Facilitating and inhibiting context factors (in analogy to Stöckli et al., 2019)*

Artifact subsystem. As elaborated above, the final documentation is part of a larger artifact system. The stakeholders make use of it at the end of the project. An artifact landscape with many possibilities to exchange knowledge beforehand impedes partially the actualization of boundary spanning capabilities (#06, #08). This goes along with alternative artifacts that offer similar affordances, e.g., one-pagers and insight statements (#03, #06). Artifacts that were more frequently used during the course of the project served as reference points for communication (#01, #04). Comparisons also include low fidelity prototypes. These more plastic artifacts supported a bidirectional sharing of information and promoted interactive discussions between the two parties. Especially, design team members thought it is more useful to share the project process with the corporate sponsor than the documentations submitted in the middle and at the end of the project (#01). In contrast, the robust and concrete nature of the final documentation promoted the sharing with third parties not involved in the project (#06, #09). The material context of the artifacts, in turn, goes along with the use practice environment. Performing use practices in the context of DT that offer boundary spanning capabilities

inhibits team members' willingness to contribute to the final documentation. For instance, insight statements and hot reports containing direct quotes that serve as a basis for argumentation. One corporate sponsor added, "they brought us this consolidated voice of the customer and put certain decisions in place when our internal business users were not ready to believe the answers that the [design] teams were bringing in front of us." (#08). Finally, face-to-face communication inhibits the actualization of the final documentation's boundary spanning capabilities. The interviewees have highlighted the essential role of personal communication and interaction to encourage close collaboration (#05, #06, #07).

Social subsystem. The stakeholders are part of a wider social subsystem. The final documentation, as well as high fidelity prototypes and one-pagers, were identified to facilitate knowledge sharing with third-parties not involved in the project (#06, #07, #09). One corporate sponsor even stated that content-wise the one-pager does not include any new information for him as he is in close contact with the team anyway (#09). Instead, they were perceived as facilitating factors to attract attention to the project within the company (#04). Further, the documentation was used for the assessment of the quality of the project (#12), which can be considered as facilitating and inhibiting. On the one hand, the documentation bridges knowledge boundaries by providing a measure for the assessment of different thought worlds. On the other hand, the main purpose is not to exchange knowledge in a collaborative manner. Overall the asymmetry of the balance of power should be considered as an inhibiting factor. Artifacts such as the final documentations are used partially politically instead of simply bridging gaps in knowledge. Moreover, insight statements and hot reports facilitated corporate sponsors' and teaching team's empathy with potential users through enhancing a shared understanding of respective needs and requirements. Besides, one-pagers are considered as facilitating factors to balance knowledge gaps regarding the methodology of DT itself by promoting understanding of the DT methodology and sharing their knowledge with other parties within the company. Finally, we found work practices that facilitate alternative ways to exchange knowledge and inhibit the use of boundary objects. For example, weekly meetings and company visits with face-to-face exchange were mentioned here (#05, #07, #07).

5. DISCUSSION

Implications for research. We address calls for research on context-specific explanations of artifact use practices (Doolin & McLeod, 2012; Huber et al., 2020; Marheineke, 2016) by elaborating how and why artifacts turn into BOs in the environment of DT projects. On a higher level, the identified use scenarios can be considered (1) to facilitate sense-making and collaborative problem solving, (2) to gain feedback and validate assumptions, (3) to make knowledge accessible and tangible for third parties, (4) and to provide applicable knowledge.

Our results reveal that rather abstract and plastic artifacts such as sketches and scribbles are used for organizing, framing, and reframing information and to make sense out of it collaboratively. These artifacts are therefore mainly used to meet the challenge of different worlds of thought (Dougherty, 1992) by enabling the creation of a common understanding of people from different backgrounds with different functions. Rather concrete and robust artifacts are utilized to share knowledge with third parties not

involved in the project and to extract learnings from the project after it is completed. Thus, that type of artifact is more likely actualized to tackle hand-over challenges and the temporal constraints of a project. Even though DT is supposed to promote empathy and open communication between the various stakeholders, the results of our study indicate that stakeholders prefer robust artifacts in a power asymmetry.

Drawing on the need for an object to be locally useful to act as a successful BO (Star & Griesemer, 1989), the results reveal that design artifacts become BOs because of their affordances – the various options for action offered to the parties involved (Gibson, 1979). Affordance theory, therefore, offers a useful construct for the discovery of object-user relationships (Wang et al., 2018) and promotes an understanding of why certain design artifacts are perceived as BOs from the perspective of the stakeholders involved. Reflecting on the emergence and actualization of affordances (Bernhard et al., 2013; Pozzi et al., 2014; Stöckli et al., 2019), allows us to infer from the subsets of the perceived services of individuals a larger set of the existing services of an object. The decisive factor for an artifact to become a BO-in-use is that it has been found to be locally useful by the individuals interacting with it.

Implications for practice. Practitioners who create and use design artifacts during DT projects, should mitigate the identified constraints and inhibit socio-material context factors while enhancing facilitating factors. Design team members and project sponsors and supervisors should consider the use of scenarios and trajectories by supporting these practices and preventing the identified constraints as well as inhibiting context factors. For instance, abstract and plastic artifacts such as sketches and scribbles help to deal with the ambiguity as the team moves from the design challenge through the design space exploration phase. The abstract nature of the artifacts can turn into concreteness as the team gathers more information they can make sense of. More robust and concrete artifacts are beneficial to communicate to and defend against third parties not involved in the project.

6. CONCLUSION

In summary, the contributions of our research are twofold. The effectiveness of a design artifact as a boundary object depends on the use practices as well as the variation and goals of the stakeholder who interacts with the artifacts. However, we identified four patterns of common use practices in the context of DT projects in an educational setup in the form of use scenarios that explain how design artifacts turn into BOs. Specifically, we showed which practices of using a design artifact result in team members tackling different challenges of DT projects. Moreover, we unpacked the dual role of object properties for the effectiveness of these practices empirically by showing (a) how variations in object properties can enable different use practices in DT that exploit these differences, and (b) how object properties are preferred by different stakeholders when knowledge boundaries are bridged beyond the project. Examining the role of artifacts through lens of affordances allowed us to see that the role and function are perceived differently according to the goals and motives of the stakeholders. Thus, the same artifact can be in the center or recede into the background. The pluralistic perspective allows for a better understanding of sources of conflict and possible issues in collaborative problem-solving.

Nevertheless, our results must be viewed in light of its limitations. First, the selected educational cases and interviewees possibly share behavioral and perceptual traits that may not be representative. However, the conditions were similar to those within companies. Project sponsors posed challenges. In analogy to dedicated design thinking teams, the teams worked on the cases. Similar to project managers, the teaching team members reviewed the teams' performance regularly. Second, the number of eleven interviews across three stakeholder groups seems to be insufficient to generalize the results. Third, the nature of knowledge boundaries between the stakeholder groups was not considered in detail. Fourth, the artifacts mainly regarded are not DT-specific due to the self-selection procedure. Thus, future research in a pure corporate environment with a larger sample size with a focus on the nature of knowledge barriers is needed.

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