Unveiling the Cloak: Kernel Theory Use in Design Science Research

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Abstract

Theory is an essential part of design research and helps us to explain what we see or guide what we design. In the paper, we shed light on how kernel theories are used in developing design principles in Design Science Research (DSR). We do this by reporting on a systematic literature review, from which we have extracted a set of six mechanisms to operationalize kernel theory. Each mechanism consists of an activity (e.g., "transform to" or "derive from") and an application point (e.g., meta-requirements or design principles) representing wherein the chain of concepts the kernel theory was used. The paper reflects on what we have learned about the use of kernel theories and translates this into recommendations and issues for further research. We provide researchers with guidance to use kernel theories more efficiently and give a big picture of the possibilities of kernel theory operationalization.

Keywords: Design principles, kernel theory, design theory, design science research

Introduction

In Design Science Research (DSR), theory has been characterized as 'nebulous' and critiqued to be a kind of fetish, resulting in excessive overemphasis of theoretical contributions (Iivari 2020) or a 'superficial cloak' to enhance theoretical legitimacy (Walls et al. 2004). In her seminal work, Gregor (2006) differentiated between five types of theories in Information Systems (IS) research: (1) analyzing, (2) explaining, (3) predicting, (4) explaining and predicting, as well as (5) design and action. Contrary to the other theory types, the theory for design and action – also called design theory – is distinctively prescriptive and seeks to guide a designer in building novel IT artifacts more efficiently (Walls et al. 1992). Since such theories have great potential, they have become one of the primary outcomes in DSR over the last few years.

As an essential ingredient for design theories, a sound theoretical bedrock is required that gives justificatory power to them and explains why they should work and why they are able to achieve a certain goal. For that purpose, Walls et al. (1992, p. 43) proposed that design theories should draw upon *kernel theories*, which are "[t]heories from natural or social sciences governing design requirements." Since then, the understanding and interpretation of what exactly a kernel theory is have changed significantly. The ambiguity has even spurred discussion on whether a kernel theory must originate from natural or social sciences (e.g., Iivari 2020). Another example includes Gregor and Jones (2007), who introduced *justificatory knowledge*, which is "nearly synonymous with kernel theory" but includes "any knowledge that informs design science research, including informal knowledge from the field" (Gregor and Hevner 2013, p. 340) proposing a more inclusive understanding. The concept of justificatory knowledge broadened the idea of kernel theory significantly from its original relatively narrow definition of kernel theory used to "govern design requirements" (Walls et al. 2004, p. 46). This results in a blurry use of the kernel theory concept, which, from our own experience, makes the application of kernel theories much more challenging, especially for inexperienced researchers.

The role and impact of kernel theories have, however, been critiqued by various scholars. For instance, Baskerville and Pries-Heje (2010, p. 281) stated that "it is unclear exactly what kernel theories contribute" and Hovorka (2010) highlighted issues, including the selection of a suitable kernel theory. Although prior research stressed the importance of kernel theories, there is a debate concerning that they might not be feasible to support design theory (Baskerville et al. 2018) or are not available in the problem domain at all (Mandviwalla 2015). Others argue that kernel theories are potential components of design theory but are not mandatory at the very least (Goldkuhl 2004; Venable 2006b). That notion is echoed by Hevner (2007, p. 90), stating that "[w]hile theories can serve as sources of creative ideas, to insist that all design research must be grounded on descriptive theories is unrealistic and even harmful to the field when good design science papers are rejected in top journals due to lack of a grounding theory."

Given the ambiguous position of kernel theories in DSR, our ultimate goal is to unveil their role in design-driven research. In attempting to do so, this paper focuses on one of the prevailing forms of formalizing (parts of) design theories, namely design principles (Chandra Kruse and Seidel 2017), and investigates how kernel theories are employed across different stages of the design principle production. We see *design principles* as a valuable object of investigation because focusing on this more conceptually narrow object (contrary to fully-fletched design theories or large-scale DSR studies) allows us to study it in-depth. It also is a pivotal component in design theories (e.g., Markus et al. 2002) and experiences significant attention in the IS community (e.g., Möller et al. 2022). Also, we can move toward understanding the specific relationship between design principles and kernel theory, following Kuechler and Vaishnavi (2012, p. 400), who observed that "no guidance on their [kernel theories] refinement to design principles is given."

Since kernel theories are used rather vaguely in IS research but still are being considered a prime component in design theory conceptualizations (Fischer et al. 2010), we shed light on kernel theory use in DSR and ask: *For what and how are kernel theories used in design principle papers?*

We investigate the above-proposed research question by reviewing the literature on kernel theories and their usage in published design principle papers. Doing this, our study has multiple contributions. First (1), we provide a cross-section and overview of kernel theories within the context of design principles. Second (2), we formalize a set of general use mechanisms that guide future researchers toward the purposes of kernel theories and how kernel theories can be applied. Third (3), we increase transparency by clarifying which design principle (component) is informed by a kernel theory. Lastly (4), we reflect on the insights collected during the study to formulate learnings and issues in the current state of kernel theory operationalization.

The paper is structured as follows: After the introduction, we outline the research background, including the role of kernel theories in design theory and the position of design principles as (nascent) design theory. We then detail our research approach and report on our findings concerning descriptive findings, mechanisms of kernel theory use with three examples, and a reflection on learnings and issues. Finally, we discuss our implications, outline limitations, and provide an outlook for further research.

Research Background: Kernel Theory and (Nascent) Design Theory

Over the years, kernel theories have been analyzed from multiple perspectives (see Table 1). For example, Fischer et al. (2010) propose a classification of Information Systems Design Theory (ISDT) schools of thought based on two dimensions: *kernel theories required for grounding* and *design theory as a key artifact*. Their analysis categorizes schools of thought into *design theory opponents* (Hevner et al. 2004; March and Smith 1995), *kernel theory pragmatists* (Goldkuhl 2004; Venable 2006a, 2006b), and *kernel theory fundamentalists* (Gregor 2006; Gregor and Jones 2007; Walls et al. 1992). The category of design theory opponents does not emphasize the importance of kernel theories at all, while the other two categories either see kernel theories as a mandatory or optional component of design theories.

Definitions	Reference
"Theories from natural or social sciences governing design requirements."	(Walls et al. 1992, p. 43)
"The underlying knowledge or theory from the natural or social or design sciences that gives a basis and explanation for the design (kernel theories)."	(Gregor and Jones 2007, p. 322)
"In theoretical grounding we are dealing with external warrants for the design theory. We are justifying the practical knowledge of the design theory with theoretical knowledge that is considered external in relation to the design theory."	(Goldkuhl 2004, p. 67)
"(...) we have broadened the scope of kernel theories to include social and design science theories as well as natural science (e.g., physics, psychology) theories."	(Kuechler and Vaishnavi 2012, pp. 397-398)

Table 1. Selected Definitions[1]

In their seminal article, Walls et al. (1992) were the first to introduce ISDTs and formulated kernel theories as mandatory components both in the design process and design product. In their conceptualization of ISDTs, kernel theories are underlying theories from natural and social sciences that are the basis for deriving meta-requirements for a meta-design and justify the design method. However, the distinction between kernel theories for the design process and design product is subject to discussion. The benefit of that distinction is not clear, and one kernel theory can govern both the design process and design product (Gregor and Jones 2007). Recently, articles indicated a variety of sources for meta-requirements (e.g., Möller et al. 2020), such as design principles themselves (Schoormann et al. 2021), exceeding the initial idea of using knowledge engraved in natural and social theories.

In their investigation of design theories, Gregor and Jones (2007, p. 322) propose a single component of *justificatory knowledge* that does not distinguish between the design process and the design product. This component is intended to explain "why a design works." In their view, *justificatory knowledge* is not restricted to governing the process and product but rather links all design theory elements together.

Goldkuhl (2004) names kernel theories but introduces the notion of *theoretical grounding* as one mechanism (next to *internal grounding* and *empirical grounding*) to substantiate design theories. In his conceptualization, theoretical grounding is the link between a design theory and 'external theories' as "(...) external warrants for the design theory" (p. 67). It refers to theories that are external to the design theory, lending explanatory power (justification) to the practical knowledge engraved in it.

Given the above, kernel theories are integral parts of most design theory conceptualizations, even though several scholars have pointed out the limitations. Mandviwalla (2015) argues that it might not always be possible in practice to apply a kernel theory 'top-down' in a design process and that artifacts might be so novel that there is no prior theory for grounding. The author also highlights the ambiguity of when to use kernel theory: whether it is more sensible and impactful in the design or the evaluation. Dwivedi et al. (2014) found that only 25 articles used kernel theories in a study of 56 articles from 2011 to 2013. Goldkuhl (2004) and Venable (2006b) both argue that kernel theories can be essential parts of design theory but do not have to be. Yet, Goldkuhl (2004) explicitly refers to 'external theories' as potential kernel theories that can be used as a deductive source to be incorporated into design theories. Others stress that kernel theories might lack concreteness and specificity to a problem at hand, i.e., how they actually inform the prescribed design (Kuechler and Vaishnavi 2012) or critique that they are hard to identify (Walls et al. 2004).

Although there was "some feeling against recognizing design principles as theory" (Gregor and Jones 2007, p. 314), today, design principles are an integral part of most conceptualizations of design theory (Baskerville and Pries-Heje 2010). They are sometimes subsumed under *nascent design theory* (e.g., Baskerville et al. 2018; Gregor and Hevner 2013). Markus et al. (2002, p. 181) explicitly state that "we present the design theory as a set of principles that offer guidance to developers." This statement is complemented by

[1] Please note: In the following, we will only use ‚Kernel Theory'.

Baskerville and Pries-Heje (2019, p. 54), finding that "researchers often express DSR theories as design principles or design theories." In line with this, Gregor and Jones (2007) propose a template to structure a design theory including two types of principles. First, *principles of form and function* address the 'product' that describes an artifact's architectural composition and functionalities. Second, *principles of implementation* prescribe the processes required to implement the artifact.

Goldkuhl (2004, p. 64) uses another concept of design principles called *prescriptive statements*, which link actions to a goal and are "(...) the core of practical knowledge and design theories." These prescriptive statements are the codification of an action that links a prescriptive action to an intended outcome (goal) that can be grounded through theory (external theories, i.e., kernel theories), empiricism, or internally. Analogously, Markus et al. (2002) draw from Walls et al. (1992) to differentiate between two sets of design principles similar to those outlined above. First, *principles governing the development process* give processual guidance in designing the artifact. Second, *principles governing the design of a system* that guides the artifact's design in terms of what it looks like and is supposed to do.

Given the above, design principles are an essential part of design theory, whose connection to the kernel theory is not clearly understood. In this respect, a differentiated consideration of design principle studies is helpful in examining the operationalization of kernel theory.

Method: A Systematic Literature Review

We performed a systematic literature review to uncover how kernel theories are used in IS papers. We divided the review process into three phases: (1) Extracting the literature, (2) filtering the literature, and (3) analyzing the literature. Below we explain each phase in detail.

Phase 1 – Extracting the literature. We opted for a systematic review (Webster and Watson 2002) to inquire about conceptualizations of kernel theories in design principle development. For that purpose, we constructed a database of papers proposing design principles. Following standard practice, we first identified a relevant database. As we analyzed papers proposing design principles, and those are usually engraved in IS research, we used AISeL to search for papers containing 'design principles' either in the *title* or *abstract* (vom Brocke et al. 2015). We focused on collecting papers from quality peer-reviewed outlets (i.e., all eight top basket journals[2]) as well as from the premier IS conferences on design-oriented publications, namely ICIS, ECIS, and DESRIST. All in all, we constructed an initial sample of 101 papers (see Table 2).

Paper selection		Papers in the final, filtered sample					
Initial	101	MISQ	2	4,2%	ECIS	10	21,28%
		JSIS	1	2,12%	DESRIST	10	21,28%
Filtered	47	JAIS	6	12,8%	EJIS	10	21,28%
		ISJ	2	4,2%	ICIS	6	12,18%
					∑	47	100%

Table 2. Literature Sample

Phase 2 – Filtering the literature. Given that not all papers developing design principles also use a *kernel theory*, we constructed a sub-sample of 47 papers that propose design principles and report on using a kernel theory. Then we followed a two-step filtering process: First, we narrowed the scope of our investigation to include papers published between 2012 and 2022. We did this to accommodate the rising interest of scholars in developing design principles and the publication of seminal papers in that period. On the one hand, key publications on design principles were produced shortly before and during this period (e.g., Chandra Kruse et al. 2015; Gregor and Jones 2007), which considered both the time publications required to penetrate the literature corpus and considered newer ones. On the other hand, recent reviews have shown that the number of publications on design principles in premiere IS outlets started to increase

[2] In the initial screening we used: ISR, MISQ, JMIS, JIT, EJIS, JAIS, ISJS, ISJ, ECIS, ICIS, and DESRIST.

around 2012 (e.g., Möller et al. 2021). Second, we screened each paper in our database for their use of kernel theories. Here, we explicitly searched for 'kernel theory' as well as adjacent terms, such as 'justificatory knowledge' (Gregor and Jones 2007). Due to the sometimes secondary nature of the kernel theory in a paper, we had to select those in which we could clearly identify their existence and use. The appendix shows the final sample and its distribution, and Table 3 gives examples of statements that lead us to inclusion.

Example literature statement	Reference
"Therefore, during the implementation of Tool D, we also worked with the theory of modular systems (Ethiraj & Levinthal, 2004; Simon, 1996) as kernel theory (....)".	(Widjaja and Gregory 2020 p. 681)
"Additionally, we draw on social response theory (Nass and Moon 2000) that has been commonly used to design and evaluate IT artifacts with human-like characteristics (Qiu and Benbasat 2009)."	(Gnewuch et al. 2017 p. 5)

Table 3. Paper Examples Referring to Kernel Theories

Phase 3 – Analyzing the literature. We iteratively constructed a concept-centric analysis schema based on the recommendations of Webster and Watson (2002). Then, we generated a coding scheme in multiple steps. As a starting point, we first coded the sample alongside three intuitive categories: *Kernel theory* (Yes/No), *Amount of kernel theories* (#number), and *Which kernel theories* (#Names). After getting a better picture, we inductively generated complementary coding categories: *Use of the kernel theory* (#Purpose) and *Where it is applied* (#Application Object). The coding procedure was done by two authors, while all authors validated the coding afterward (i.e., through coding a sub-sample) by discussing deviations and reaching a consensus about the coding.

Table 4 lists examples of our coding process concerning the application point (e.g., meta-requirements) and the mechanism (e.g., 'derive from'). The examples illustrate the heterogeneity in how kernel theories are operationalized, showing many possible configurations of mechanisms and application objects. Below, we discuss three in-depth examples in the studies of Gregor et al. (2014), Chanson et al. (2019), and Feine et al. (2020b). In these examples, we outline in detail how the authors operationalized kernel theories in design principle development. We selected these examples since they use two of the more complex mechanisms in *warrant by* and *transform to,* and perhaps the most basic one in *derive from*. They are also good examples of the plurality of kernel theory operationalization since two studies use multiple and diverse kernel theories, while the third example uses one kernel theory.

Citation	Kernel theory	Example literature statements	Coding
(Ruoff and Gnewuch 2021, p. 8)	Theory of Effective Use	"Consequently, we formulate two meta-requirements (MR) based on the dimensions of effective use: Multimodal BI&A systems should provide a high level of transparent interaction (MR1) and representational fidelity (MR2)".	**Derive** *Meta-Requirements* **from Kernel Theory**
(Babaian et al. 2018, p. 194)	Collaboration Theory	"These design principles were derived by analyzing the findings of the field studies within the context of ERP systems, with collaboration theory serving as a guide."	**Analyze data with Lens** to derive *Design Principles* from **Kernel Theory**
(Chatterjee et al. 2018, p. 674)	Fogg's (2009) theory of persuasion	DP4 (Tailored trigger): The daily feedback persuasive messages must be fresh, not boring, and tailored so that patient is eager to receive them and remains engaged with the system (Fogg & Adler, 2009). This principle is derived from Fogg's theory.	**Derive** *Design Principles* **from Kernel Theory**

(Meth et al. 2013, p. 7)	Information Processing Theory	"This hypotheses is additionally supported by Information Processing Theory (Miller 1956), explaining that human information processing is restricted by cognitive limitations. Information systems supporting elicitation activities through automation can help to overcome or at least reduce these limitations resulting in a larger amount of identified task elements in a fixed time period."	**Warrant** *Design Principles* **by Kernel Theory**
(Pöhler et al. 2021, p. 4)	Theory of Personal Engagement and Dis-engagement at Work	"Then, we derive meta-requirements (MRs) for our artifact by incorporating empirical findings. Based on these and guided by the theory of personal engagement and disengagement at work (Kahn 1990), we propose four DPs that we instantiate within the next section."	**Transform** *Meta-Requirements* **to** *Design Principles* **through Kernel Theory**
(Widjaja and Gregory 2020, p. 681)	Theory of Modular Systems	"Synthesizing the insights (Step 18) from joint problem solving with Company 4 and Company 5 and prior kernel theory on modular systems yielded a further refinement of the design principle "decomposability" (DP-D3)."	**Refine** *Design Principles* **with Kernel Theory**
(Feine et al. 2020a, p. 134)	Similarity Attraction Theory	"Similar features are required in DF1, DF4, and DF5 that require the ECB to ask the user for their preferred language style. These results are in line with the similarity attraction theory."	**Warrant** *Design Features* **by Kernel Theory**
(Pan et al. 2020, p. 8)	Affordance	"Next, we refined the preliminary requirements into a general set of requirements in the forms of required affordances."	**Refine** *Meta-Requirements* **with Kernel Theory**
(Vössing et al. 2019, p. 4)	Useful Transparency	"Hence, we want to derive principles for the design of information systems. We explore this objective by iteratively developing an artifact (...) evaluating it against two testable propositions: "Accessible process information in an information systems leads to useful transparency." (P1), and "Useful transparency in an information system leads to increased process performance." (P2)."	**Evaluate** *Artifact* **through Kernel Theory**
Mechanisms: **Activity** *Application Point* **Kernel Theory**			

Table 4. Coding Examples for Mechanisms and Application Objects

Findings: Kernel Theories in Design Principle Development

What: Sample Overview

As a result of our research procedure, we constructed a sub-sample of 47 papers proposing design principles by making use of kernel theories. To the extent that we also filtered out papers that use kernel theories but could not clearly assign the usage, the final sample is reduced by these papers and those that do not use kernel theory. Subsequently, about 46,5% of our initial sample reported on kernel theories so that we could use them in our study. Most papers in our sample draw from one kernel theory (over 80%).

Authors use kernel theories very differently. Some use 'typical' theories, such as Cognitive Load Theory or Information Processing Theory, while others use frameworks (e.g., Smart Service Systems). We also observed that some papers use more than one kernel theory and apply them to different design principles in a set (e.g., see the examples of Gregor et al. 2014 and Chanson et al. 2019 in the next section). What was striking was the substantial heterogeneity of the kernel theories used. Only a few were used twice or more, but most were used only once. The numerically prevalent theories occurred three times in our sample, namely: Service-Dominant Logic, Cognitive-Load-Theory, Diffusion of Innovation, and Intervention Theory. Four kernel theories were used twice in Activity Theory, Media Richness Theory, Self-Determination Theory, and Principal-Agent Theory. All other kernel theories were used once, resulting in the vast majority in our sample (e.g., Theory of Privacy or Spatial and Navigational Theory). See the appendix for the entire sample of kernel theories per paper and their individual cumulative distribution.

How: Mechanisms for Kernel Theory Use

In Table 5, we summarize the related concepts we looked for in analyzing the papers. As a first step, design principle development often requires eliciting requirements. Authors vary in terminology, with some using design requirements (e.g., Meth et al. 2015), while others use meta-requirements (e.g., Gaß et al. 2013). We subsume these under requirements. Second, design principles themselves are an application object, as they are, for example, subject to kernel theory-based refinement or derivation. Third, while this is not a mandatory task, some authors use design features to de-abstract principles into specific implementations (e.g., Siering et al. 2021). Finally, the situated implementation of an artifact is intended to address the design principles. Each of these concepts represents a different stage of abstraction, starting from the most abstract and general (requirements) to a specific, situated implementation (artifact). Following our coding approach, we identified six mechanisms of how to use kernel theories (see Figure 1). We provide a graphical visualization of the mechanism, an explanation, and the application objects to describe where a mechanism is applied. We cannot claim that these are the only ways to use each mechanism, yet these are the ones that we found evidence for. Please note that these mechanisms are most certainly not exclusive.

Related Concepts	Definition
Requirements	Requirements for a design. Please *note*: authors use different terminologies, such as design requirements or meta-requirements.
Design principles	Codified, abstracted design knowledge as linguistic statements.
Design features	Specific features to be implemented in an artifact.
Situated instantiation/Artifact	Instantiated artifact in a specific design context.

Table 5. Related Concepts to Design Principles (Meth et al. 2015; Wache et al. 2022)

Derive from (1). The first mechanism refers to kernel theories being used as a source to extract an object of interest directly. Subsequently, a suitable kernel theory is selected from which authors directly derive, for instance, meta-requirements and design principles. As an example, Ruoff and Gnewuch (2021) derive two meta-requirements for designing multimodal BI&A systems from the Theory of Effective Use that is, in turn, developed further into design principles for multimodal BI&A systems. Seidel et al. (2017) derive preliminary design principles based on "(…) salient affordances required in the sensemaking process." In consequence, this mechanism allows for deriving (parts of) objects from selected theory.

Analyze with lens (2). While some authors derive concepts directly, others employ kernel theories in the form of a theoretical lens. This lens allows them, for example, to analyze or frame data. In these cases, data are analyzed to adhere to the conceptual borders of a theory or to guide the analysis based on concepts in theory. For illustration, Babaian et al. (2018) derive design principles based on field studies, both drawing from Enterprise Resource Planning (ERP) systems and Collaboration Theory as kernel theory. Hoffmann et al. (2017) use Activity Theory as a guide to identifying systematic tensions in their empirical interview data to elicit requirements from them, which are the foundation to derive design principles addressing them. This process is consistent with the understanding of Niederman and March (2019) of the theoretical lens, namely that it helps to theorize (e.g., design principles or meta-requirements) based on a data foundation.

Warrant by (3). Other researchers use kernel theories to warrant why design principles or meta-requirements should work or are valid. Gregor et al. (2014) derive four design principles for a sweet spot change strategy in e-Government change in the case of Bangladesh. The authors provide *grounding* (i.e., kernel theory) for each design principle individually. For instance, the design principle *Engage influential* *stakeholders* is grounded in Rogers (2003)'s Innovation Theory. They draw from generalized statements and rationalize them in the context of their design principle, i.e., that it is vital to empower decision-makers as they have the power to influence others. The design principle of *Tailor the intervention to suit the LDC with existing knowledge as a base* is grounded in "the work in the ICT4D literature," discussing how interventions work in the least developed countries.

Refine with (4). This mechanism for refinements is concerned with reframing or improving design principles and meta-requirements by means of a kernel theory. As an illustrative example, Morana et al. (2018) report on a DSR study designing a process guiding systems artifact and the derivation of corresponding design principles. In the second design cycle, they draw from Spatial and Navigational Theory to 'update' existing design principles from the first design cycle. Pan et al. (2020, p. 7) refine a preliminary set of requirements to a more general set of requirements "in the forms of required affordances."

Transform to (5). Some papers make use of kernel theories to transform one object into another object, usually requirements into design principles. A notable exception is Coenen et al. (2018, p. 252), who use Comparative Judgement to "(...) identify design features to address the design requirements." Then, the authors develop design principles based on inductive reasoning using the design features as a starting point. Pöhler et al. (2021) employ the Theory of Personal Engagement and Disengagement and empirical findings to progress from a set of meta-requirements to four design principles.

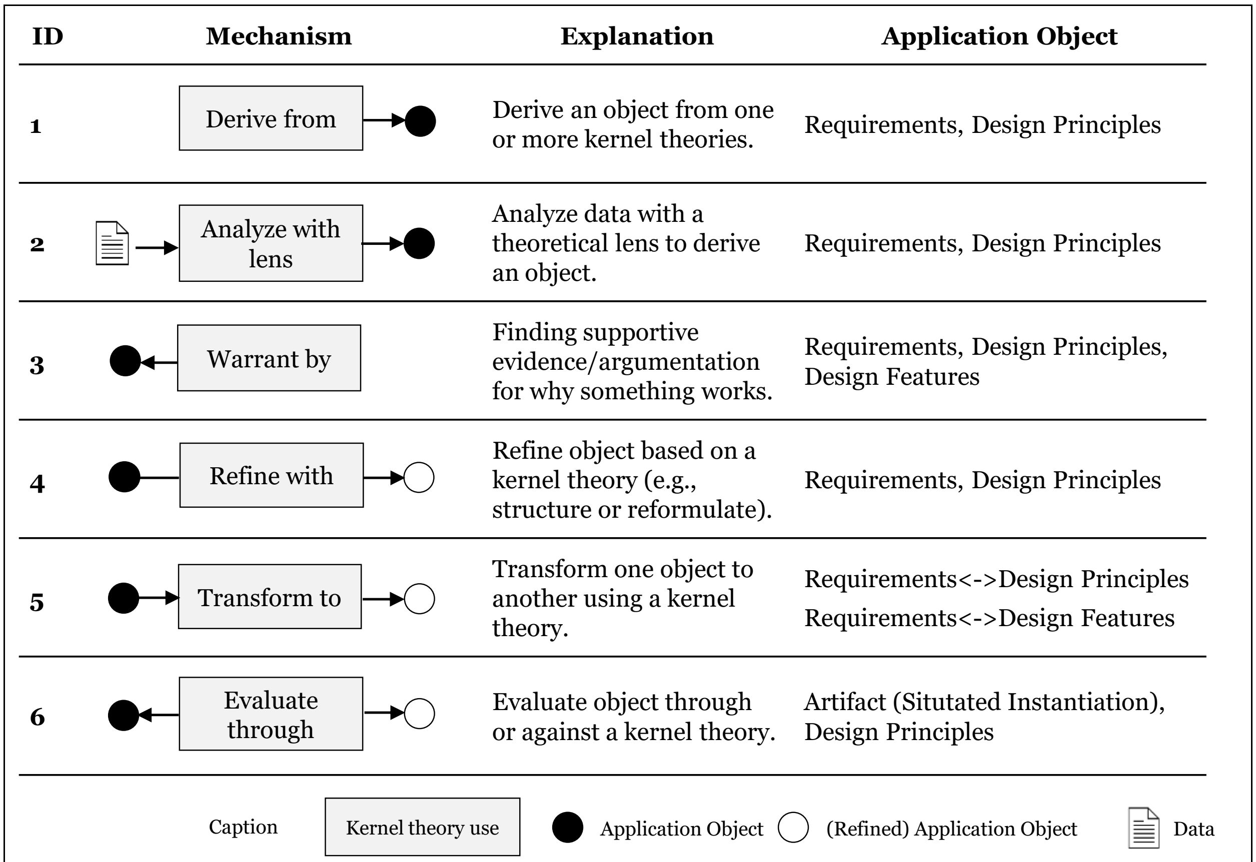


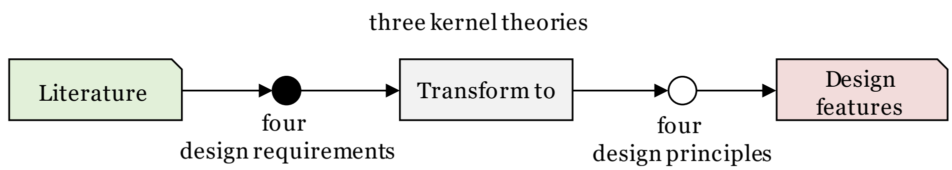
Figure 1. Synthesis of Kernel Theory Use

Evaluate through (6). Lastly, our sample discloses papers using kernel theories to evaluate design principles or artifacts. Vössing et al. (2019) propose a set of design principles for facilitating useful transparency that they instantiate in a prototypical artifact. Since their artifact intended to facilitate useful transparency (which is the kernel theory), they performed an evaluation based on two testable propositions regarding useful transparency through focus groups with domain experts. As a second example, Stierle et al. (2020) propose five design principles that they equip with metrics derived from various sources (e.g., Cognitive Load Theory or Graph Aesthetics) and reference values, which can be used, i.e., for evaluating the applicability of the design principles.

Demonstration of Operationalization Mechanisms

To demonstrate the applicability of our use mechanisms, we now provide three different examples from our literature sample of available design principle papers[3].

In a first example, Chanson et al. (2019) use kernel theories to progress from literature-based design requirements to design principles (see Figure 2). They propose four design requirements and four design principles and use three kernel theories, i.e., the Theory of Information Asymmetry, the Theory of Privacy, and the DeLone and McLean Model of Information Systems Success. DR1 demands tamper-resistant data generation, processing, and exchange. The authors use the Theory of Information Asymmetry to generate two design principles based on DR1. From this, they derive the need to implement certification, given that manipulation of sensor data is only identifiable when it is obvious. Subsequently, there is a need to protect the data chain from source to sink through adequate encryption and certification. Similarly, DP2 prescribes cross-validating the certification of sensor data, addressing potential manipulations before data provision (i.e., the sensor). To derive DP3, the authors refer to Westin (1968)'s Theory of Privacy and tailor the four cornerstones of privacy and the rights of a data owner to retain full control of their data to sensor data based on DR2. Since DR3 and DR4 address issues of success rather than privacy or control, the authors shift their kernel theories and draw from DeLone and McLean (2003)'s model of information systems success to derive a design principle ensuring that positive effects are not canceled by negative effects (e.g., resource-intensiveness and scalability). DP4 prescribes a linearly scalable system architecture for the certified data.



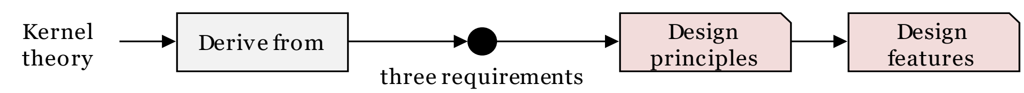
Application Object 1	Mechanism	Application Object 2	Kernel Theory
DR1: Enable tamper-resistant data generation, processing and exchange	Transform to	**DP1**: Sensor data is certified on the basis of the source to sink protection (DR1)	Theory of Information Asymmetry
DR2: Enable privacy preserving data generation, processing and exchange		**DP2**: Sensor data is certified on the basis of cross-validation (DR1)	
DR3: Enable large data volume throughput		**DP3**: Data-owners determine when and to what extent their certified data is communicated to others (DR2)	Theory of privacy
DR4: Ensure economic feasibility		**DP4**: Data is certified on the basis of a linearly scalable system architecture (DR3+DR4)	DeLone and McLean Model of Information System Success

Figure 2. Illustrative Example by Chanson et al. (2019)

In another example, Feine et al. (2020b) propose three design principles for interactive chatbot development systems (see Figure 3). They ground their design in the Interactivity Effects Model, which is their justificatory knowledge to "derive requirements (REQs) that define the overarching goals of the proposed design (Gregor and Jones 2007)" (Feine et al. 2020b, p. 3). Based on these requirements, they derive design principles. Subsequently, the authors use the mechanism *derive from* to generate the application object *requirements*. The model proposes three pillars of interactivity features: modality

[3] The coloured boxes in Figure 2 to Figure 4 below are additional elements to help understand the bigger picture of the study. Light green = additional preceding activity, light red = additional subsequent result.

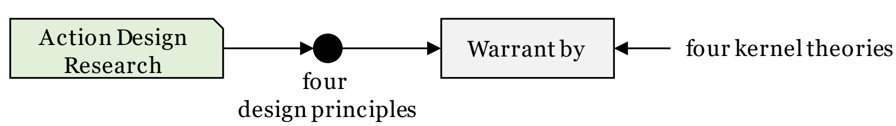
interactivity, message interactivity, and source interactivity. After explaining each pillar in detail, the authors tailor these interactivity features to chatbot development systems and formulate three requirements, i.e., that "(…) interactive chatbot development systems should have a high level of modality interactivity (REQ1), message interactivity (REQ2), as well as source interactivity (REQ3).



Application Object 1	Mechanism	Kernel Theory
Interactive chatbot development systems should have a high level of… **RQ1:** …modality interactivity	Derive from	Interactivity Effects Model
RQ2: …message interactivity		
RQ1: …source interactivity		

Figure 3. Illustrative Example by Feine et al. (2020b)

Lastly, Gregor et al. (2014)'s Action Design Research (ADR) study derives four design principles for sweet spot change strategy in the least developed countries (LDC). The authors reflect upon what they have done and formulate four interlinked design principles. Each design principle provides one 'grounding' working as a kernel theory, warranting why the design principle works. The first design principle prescribes searching for key inhibitors, which, in their case, are the lack of knowledge and the attitude of senior decision-makers. To ground the design principle, the authors refer to the foundations of sweet spots. The second design principle prescribes engaging influential stakeholders due to the number and structure of the population in the case country. DP2 is grounded in Rogers (2003)'s Innovation Theory, where he "(…) stressed the mobilization of 'opinion leaders'(…)" (Gregor et al. 2014, p. 664). The third design principle prescribes that local knowledge is mandatory and is grounded in (similar to DP2), Rogers (1995)'s recommendations. Last, the fourth design principle is about tailoring the intervention to the conditions of the LDC using existing knowledge. This design principle is grounded in the "(…) work from the ICT4D literature that shows how interventions based uncritically on practices, systems, and values from one culture will likely not translate directly to another culture (…)" (p. 665). Figure 4 summarizes how kernel theory is used in this illustrative case.



Application Object 1	Mechanism	Kernel Theory
DP1: Identify and act on the sweet spot(s)	Warrant by	Sweet spot concept
DP2: Engage influential stakeholders		Rogers (2003)'s innovation theory
DP3: Local knowledge is mandatory		Rogers (1995)'s recommendations
DP4: Tailor the intervention to suit the LDC with existing knowledge as a base		Literature on ICT4D

Figure 4. Illustrative Example by Gregor et al. (2014)

Discussion

From our literature analysis, we reflect upon what we have learned to formulate recommendations for future operationalization of kernel theories, as well as issues for subsequent research.

The spectrum of kernel theory utilization is highly heterogeneous. Contrary to Walls et al. (1992)'s initial proposition, kernel theories are not exclusively used to derive meta-requirements and do not solely originate in natural and social sciences. Instead, authors have extended the 'playing field' drawing from a diverse field of underpinning theoretical knowledge and using it in different stages of the design principle development process. Reflecting on our study, we propose a set of learnings in terms of kernel theory operationalization in design principles development. Similar to what we outlined in the introduction, namely, that the role of theory is often challenging to grasp, comprehend, and, most importantly, operationalize, we also noticed this in our study. First, in terms of **clarity (1)**, studies proposing design principles should make unambiguously clear if and which kernel theory was used. Second, for **transparency (2)**, authors should state how many kernel theories and why they were selected to inform a part or multiple parts of design principle development (or a DSR project in general). Third, in terms of **understandability (3)**, authors should indicate which part of design principle development is informed by which kernel theory (e.g., meta-requirements or design principles derived from kernel theory).

Next to these learnings, we formulate a set of issues that are potentially fertile soil for further research. First, our study shows heterogeneity in how many kernel theories underlie the design principles. For example, Gregor et al. (2014) use four individual kernel theories to ground each of their four design principles. While we have noticed this, we have not analyzed whether using one or multiple kernel theories has advantages or disadvantages in formulating design principles. Staying with the same example, we find a strong diversity in what is defined as a *kernel theory*. For instance, Gregor et al. (2014) use Rogers (2003)'s theory of innovation diffusion as well as literature findings as separate kernel theories to ground separate design principles. Second, our analysis shows a range of 'kernel theories' used, ranging from classical theories to foundational knowledge from the literature. What we cannot say, however, is whether a qualitative or gradual difference emerges as a result. For example, it would be interesting to investigate whether grand theories as kernel theories have a different 'validity' than 'just' literature findings. Third, the authors use different application objects for kernel theories in design principle development. An interesting question would be whether it makes a difference where the theory is applied (e.g., in requirements or design principles) or whether it is applied in one or multiple stages of design principle development.

Naturally, our work is subject to **limitations**. Given the nature of literature reviews, we may have missed articles that potentially would benefit the study. Our study only accounts for a snapshot of the literature published in the last ten years. This opens the potential to build on our work and find how kernel theory use differs between our sample and papers outside of this time period. Although we applied procedures to ensure the validity of the coding (e.g., finding consensus among four authors), the literature analysis process remains qualitative, which means that other researchers might interpret some papers differently. The paper focuses on design principles to narrow the field of investigation. However, we see our work as a valuable first fragment of understanding kernel theories in DSR in general. Future studies could broaden the spectrum to fully-fletched design theories or projects that do not develop design principles. While we derived the mechanisms inductively and demonstrated their applicability through retrospective use, additional evaluation to indicate their value and usefulness can be executed. Lastly, our work only investigated kernel theories and their utilization based on what could be extracted at face value and does not cover kernel theories that are implicitly used. In short, we could only analyze kernel theories that the authors explicitly mentioned, whereas inherent, underlying theories from computing, mathematics, or physics could not be inferred.

Contributions and Outlook

Our work primarily addresses researchers that conduct DSR projects and also strive to develop design principles using kernel theories. Subsequently, the most significant contribution is making kernel theory use more 'tangible' by outlining a set of six mechanisms. With this, we answer previous criticisms (e.g., Iivari 2020) and highlight the vagueness of how kernel theories are and should be used. The mechanisms give clear instructions on what can be done with kernel theories and which part of design theory they can address.

Given the above, our work **contributes** to strengthening rigor in design principle development when it comes to using kernel theories. Especially, we see value for novel researchers that try to penetrate the rather complex field of design theory and kernel theories since we offer intuitive mechanisms that can be applied easily. Also, reviewers profit from our work since authors can transparently label how they used kernel theories instead of merely mentioning that they have done so. Since we have noticed that most kernel theories are only used once or very few times, we see a contribution in providing a list of kernel theories used in the past. Researchers can draw from them and find inspiration for fitting kernel theories, which is a relevant problem (see Section 1). To summarize, our work can assist researchers in their DSR projects to utilize kernel theories more effectively and efficiently since we unveil and provide easy-to-implement mechanisms on how to use them. Given that knowledge accumulation is a highly relevant topic in DSR and IS research as a whole (e.g., vom Brocke et al. 2020), we see the above as a significant contribution. Lastly, we hope to add to ongoing discussions (see our introduction) on the place of kernel theories in DSR.

Our paper offers multiple ways for **future research**. First, while we provide mechanisms, we do not assess whether they should be used in a specific way or order or address a particular application object. A potential next step would be to integrate the mechanisms into a larger framework for kernel theory selection and operationalization. This would also address the criticism that we have outlined in the introduction (i.e., it is not easy to find suitable kernel theories or any kernel theories at all) and could provide users with decision criteria for using such theories. Second, the mechanisms could be investigated using a spectrum of complementary research methods (e.g., interview studies or questionnaires) to substantiate what we have found in the literature and mitigate the room for qualitative assessment on our part. A promising avenue is to engage with researchers and extract first-hand knowledge on how they used kernel theories generally but also how they use our set of mechanisms. By performing, for instance, think-aloud studies, it could be explored whether researchers select mechanisms intuitively as part of an ongoing process that takes place in a researcher's mind or through joint discussions among a team of researchers. This could also help to uncover 'hidden' kernel theories that guide the design processes implicitly.

To summarize, our research set out to investigate how to operationalize kernel theory. In the spirit of one of the most famous quotes regarding the role of theory in research attested to Kurt Lewin, we hope that our work has made, paradoxically as it may sound, theory a little more practical since: *"there is nothing as practical as a good theory."* (Lewin 1943, p. 118)

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Appendix: Overview of Articles and their Kernel Theories

Citation	Kernel Theories	Citation	Kernel Theories
(Kane et al. 2020)	Emancipatory Pedagogy (1)	(Coenen et al. 2018)	Comparative Judgment (1)
(Widjaja and Gregory 2020)	Theory of Modular Systems (1)	(Chatterjee et al. 2018)	Theory of Persuasion (1)
(Kolkowska et al. 2017)	VBC Theory (1), Social Action Theory (1), Theory of Organisational Learning (1), Theory of Tacit Knowledge (1)	(Babaian et al. 2018)	Collaboration Theory (1), ISO Definition of Usability (1)
(Cvijikj et al. 2015)	Motivation Theory (1), Extended Unified Theory of Acceptance and Use of Technology (1), Victimization Theory (1), Social Control Theory (1)	(Zschech et al. 2021)	Technology Acceptance Theory (1), Principal-Agent Theory (2), Signalling Theory (1), Algorithm Aversion (1)
(Morana et al. 2018)	Spatial and Navigational Theory (1)	(Wiethof et al. 2020)	Multimotive Information Systems Continuance Model (1)
(Tuunanen and Peffers 2018)	Personal Construct Theory (1), Theory of Disability (1), Diffusion of Innovations (3), Social Actor Theory (1), Media Richness and Information Synchronicity Theory (2)	(Wache and Dinter 2021)	Smart Service Systems (1)
		(Vössing et al. 2019)	Useful Transparency (1)
(Lee et al. 2018)	Prevention Motivation Theory (1), Analogical Social Norm Theory (1)	(Vogel et al. 2021)	Media Richness Theory (2), Theory of Organizational Creativity (1)
(Gaß et al. 2013)	Technology-to-Performance Chain (1), Cognitive-Load-Theory (3), Activity Theory (2), Diffusion of Innovation Theory (3)	(Stierle et al. 2020)	Information Theory (1), Business Process Modelling (1), Process Mining (1), Graph Aesthetics (1), Cognitive Load Theory (3)
(Chanson et al. 2019)	Information Asymmetry (1), Theory of Privacy (1), The DeLone and McLean Model (1)	(Ruoff and Gnewuch 2021)	Theory of Effective Use (1)
(Randolph et al. 2022)	Media Synchronicity Theory (1)	(Lechler et al. 2019)	Self-Determination Theory (2), Literature on Feedback, Persuasive Systems (1)
(Asatiani et al. 2021)	Organizational Discontinuity Theory (1)	(Hoffmann et al. 2017)	Activity Theory (2)
(Piccoli et al. 2017)	Intervention Theory (3)	(Gröger and Schumann 2014)	Principal-Agent Theory (2), Task Closure Theory (1)
(Meth et al. 2013)	Information Processing Theory (1)	(Ortbach et al. 2014)	Knowledge Management (1), Gamification (1), Social Presence (1), Social Network Theory (1)
(Feine et al. 2020b)	Interactivity Effects Model (1)	(Hönigsberg 2020)	Service-Dominant Logic (3)
(Döppner et al. 2016)	Decision-Making Theory (1)	(Herterich 2017)	Service-Dominant Logic (3)
(Siering et al. 2021)	Behavioral Finance Theory (1)	(Feine et al. 2020a)	Similarity Attraction Theory (1)
(Meth et al. 2015)	Decision Support Theory (1)	(Dickhaut et al. 2020)	Cognitive-Load-Theory (3)
		(Gregor et al. 2014)	Sweet Spot Concept (1), Theory of Innovation (3), Literature on ICT4D (1)
(Seidel et al. 2017)	Theory of Cognitive Dissonance (1), Sensemaking Theory (1)	(Dellermann et al. 2017)	Opportunity Creation Theory (1)
(Recker 2021)	Representation Theory (1)	(Blaschke et al. 2017)	Service-Dominant Logic (3)
(Piccoli et al. 2020)	Intervention Theory (3)	(Aljaroodi et al. 2017)	Behavior Change Theory (1), Color Theory (1), Gestalt Theory (1)
(Pan et al. 2020)	Affordances (1)	(Alharbey and Chatterjee 2019)	Health Belief Model (1), Behavior Change Support System (1)
(Nguyen et al. 2020)	Intervention Theory (3)	(Pöhler et al. 2021)	Theory of Personal Engagement and Disengagement (1)
(Liu et al. 2017)	Prospect Theory (1), Hyperbolic Discounting (1), Agency Theory (1), Media Characteristics (1), Social Cognitive Theory (1), Optimal Simulation (1), Job Characteristics Theory (1), Flow Theory (1), Self-Determination Theory (2), Social Comparison Theory (1), Social Influence and Norms (1)		

Table A1. Kernel Theories per Article and the Cumulative Number of Kernel Theories in the Sample