Introduction to Design Science Research

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Introduction to Design Science Research[1]

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Abstract

Design Science Research (DSR) is a problem-solving paradigm that seeks to enhance human knowledge via the creation of innovative artifacts. Simply stated, DSR seeks to enhance technology and science knowledge bases via the creation of innovative artifacts that solve problems and improve the environment in which they are instantiated. The results of DSR include both the newly designed artifacts and design knowledge (DK) that provides a fuller understanding via design theories of why the artifacts enhance (or, disrupt) the relevant application contexts. The goal of this introduction chapter is to provide a brief survey of DSR concepts for better understanding of the following chapters that present DSR case studies.

Introduction to Design Science Research

The Design Science Research (DSR) paradigm has its roots in engineering and the sciences of the artificial (Simon 1996). It is fundamentally a problem-solving paradigm. DSR seeks to enhance human knowledge with the creation of innovative artifacts and the generation of design knowledge (DK) via innovative solutions to real-world problems (Hevner, March, Park, & Ram 2004). As such, this research paradigm has generated a surge of interest in the past twenty years, specifically due to its potential to contribute to fostering the innovation capabilities of organizations as well as

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contributing to the much needed sustainability transformation of society (Watson, Boudreau, & Chen, 2010; vom Brocke, Watson, Dwyer, Elliot, & Melville, 2013; vom Brocke, Winter, Hevner, & Maedche 2020).

The goal of a DSR research project is to extend the boundaries of human and organizational capabilities by designing new and innovative artifacts represented by constructs, models, methods, and instantiations (Hevner et al. 2004, Gregor & Hevner 2013). DSR aims to generate knowledge of how things can and should be constructed or arranged (i.e., designed), usually by human agency, to achieve a desired set of goals; referred to as design knowledge (DK). For example, DK in the Information Systems (IS) discipline includes knowledge of how to structure and construct a database system, how to model business processes, how to align IS with organizational strategy, how to deliver data analytics for effective decision making (e.g. Becker et al. 2015), as well as how to use information technology to support sustainable practices (Seidel et al. 2013, vom Brocke & Seidel 2012). DSR results in IS have been shown to create significant economic and societal impact (Gregor & Hevner 2013, vom Brocke et al. 2013). Beyond the IS field, DSR is a central research paradigm in many other domains including engineering, architecture, business, economics, and other information technology-related disciplines for the creation of novel solutions to relevant design problems.

In the following, we introduce some essential frameworks and conceptualizations that we deem important in order to provide foundations on how to conduct DSR to scholarly standards. The cases presented in this book use such fundamentals in order to structure and document their DSR projects.

The DSR Framework

Figure 1 presents a conceptual framework for understanding, executing, and evaluating design science research (Hevner et al. 2004). The environment defines the problem space in which the phenomena of interest reside. It is composed of people, organizations, and existing or planned technologies. In it are the goals, tasks, problems, and opportunities that define needs as they are perceived by stakeholders within the organization. Needs are assessed and evaluated within the context of organizational strategies, structure, culture, and existing work processes. They are positioned relative to existing technology infrastructure, applications, communication architectures, and development capabilities. Together these define the "research problem" as perceived by the researcher. Framing research activities to address real stakeholder needs assures research relevance. The knowledge base provides the raw materials from and through which DSR is accomplished. The knowledge base is composed of Foundations and Methodologies. Prior research and results from reference disciplines provide foundational theories, frameworks, instruments, constructs, models, methods, and instantiations used in the build phase of a research study. Methodologies provide guidelines used in the evaluate phase. Rigor is achieved by appropriately applying existing foundations and methodologies.

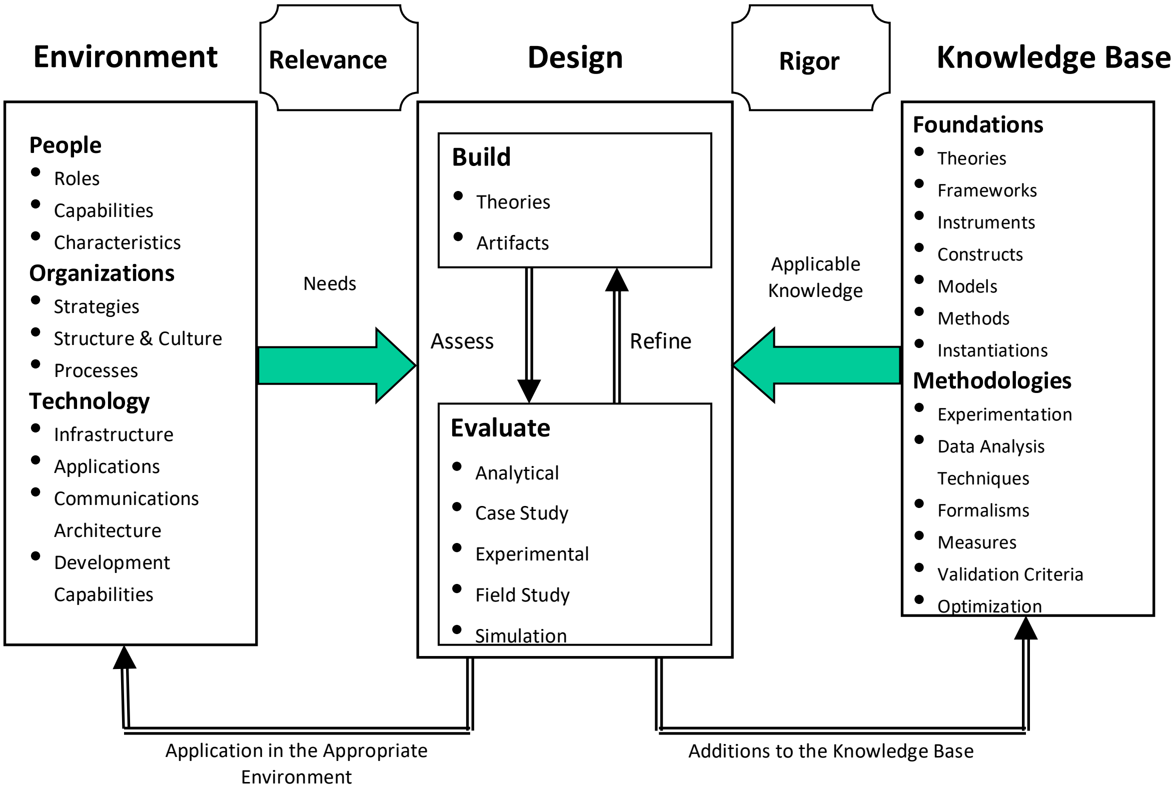

Figure 1: Design Science Research Framework (Adapted from (Hevner et al. 2004))

DSR studies relevant problems in the real-world environment with various application domains. Research links to a "need" for solutions to be empirically investigated with people in organizations using specific technology. Often, the analysis of the business environment and the derivation of specific needs to be solved build the starting point of a DSR project. However, also situations exist in which needs have already been studied and can be taken from extant research. DSR analyses the (academic) knowledge base in that it studies to which extent design knowledge is already available to solve a problem of interest. Such knowledge can take the form of theories, frameworks, instruments or design artifacts, such as constructs, models, methods or instantiations. In case knowledge is already available to solve a problem identified, this knowledge can be applied following "routine design", which does not constitute DSR. Else, DSR sets out to create an innovative solution to the problem, which, in most cases, builds on existing parts of a solution and combines, revises, and extends extant design knowledge. The design activities comprise of "build" and "evaluate" activities, typically following multiple iterations. In course of a DSR study, diverse research methods are applied, including those well established in social science research, such as interviews, surveys, literature reviews, or focus groups.

DSR Process

The performance of DSR projects has been based on several process models, such as Nunamaker, Chen, & Purdin (1991), Walls, Widmeyer, & El Sawy (1992), Hevner (2007), and Kuchler & Vaishnavi (2008). The mostly widely referenced model is one proposed by Peffers, Tuuanen, Rothenberger, & Chatterjee (2008). The design science research methodology (DSRM) process model is shown in Figure 2. This DSR process includes six steps: problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation, and communication; and four possible entry points:

problem-centered initiation, objective-centered solution, design and development-centered initiation, and client/context initiation. A brief description of each DSR activity follows.

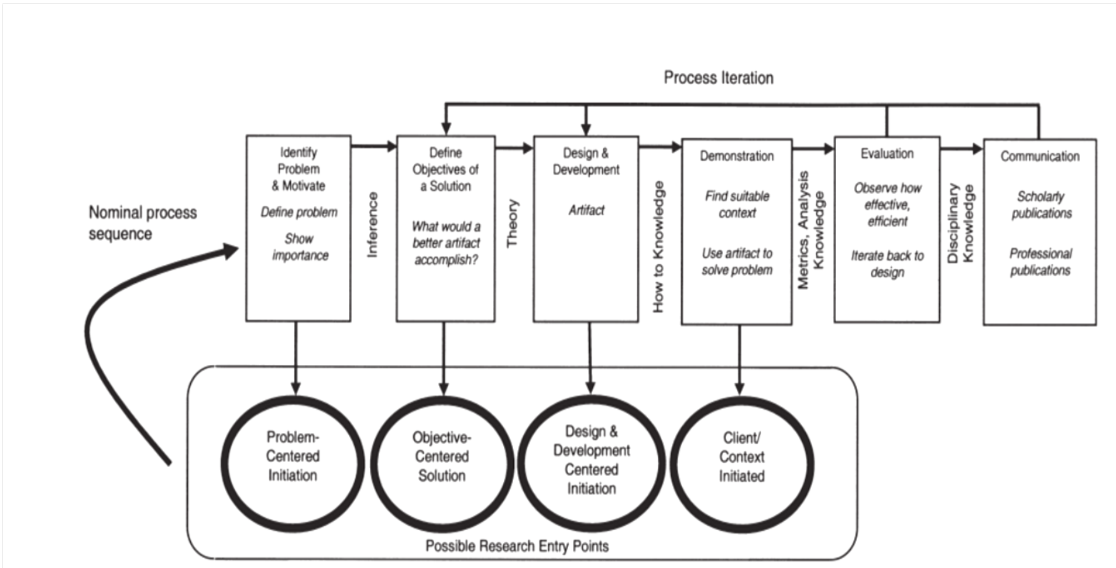

Figure 2: DSR Methodology Process Model (Adapted from Peffers et al. (2008))

Activity 1. Problem identification and motivation. This activity defines the specific research problem and justifies the value of a solution. Justifying the value of a solution accomplishes two things: it motivates the researcher and the audience of the research to pursue the solution and it helps the audience to appreciate the researcher's understanding of the problem. Resources required for this activity include knowledge of the state of the problem and the importance of its solution.

Activity 2. Define the objectives for a solution. The objectives of a solution can be inferred from the problem definition and knowledge of what is possible and feasible. The objectives can be quantitative, e.g., terms in which a desirable solution would be better than current ones, or qualitative, e.g., a description of how a new artifact is expected to support solutions to problems not hitherto addressed. The objectives should be inferred rationally from the problem specification.

Activity 3. Design and development. An artifact is created. Conceptually, a DSR artifact can be any designed object in which a research contribution is embedded in the design. This activity includes determining the artifact's desired functionality and its architecture and then creating the actual artifact.

Activity 4. Demonstration. This activity demonstrates the use of the artifact to solve one or more instances of the problem. This could involve its use in experimentation, simulation, case study, proof, or other appropriate activity.

Activity 5. Evaluation. The evaluation measures how well the artifact supports a solution to the problem. This activity involves comparing the objectives of a solution to actual observed results from use of the artifact in context. Depending on the nature of the problem venue and the artifact, evaluation could take many forms. At the end of this activity the researchers can decide whether to iterate back to step three to try to improve the effectiveness of the artifact or to continue on to communication and leave further improvement to subsequent projects.

Activity 6. Communication. Here all aspects of the problem and the designed artifact are communicated to the relevant stakeholders. Appropriate forms of communication are employed depending upon the research goals and the audience, such as practicing professionals.

DSR Evaluation

The process of conducting DSR has been further developed in many ways, specifically paying attention to the evaluation activities and allowing for a more concurrent and fine-grained evaluation of intermediate steps in the design process. While it is well-understood that also the

Peffers et al. (2008) process should and would be conducted iteratively, evaluation only takes place after design, development and demonstration activities; missing out on the opportunity to inform the design in an early stage of the research process.

Sonnenberg and vom Brocke (2012) conceptualize concurrent evaluation according to different aspects of design as shown in Figure 3. They build on prior work describing DSR activities within the overall DSR process, arguing that each of these activities progresses toward the intended artefacts differently and thus offer potential for concurrent (or formative) evaluation. Such evaluation can mitigate risk (Venable, vom Brocke, & Winter 2019), as early feedback on the minute steps leading to the eventual artefact can be incorporated into the design process. The authors also assert that this type of evaluation can be more specific and better directed if the evaluation focuses on the different aspects of design when relevant decisions are being made during the design process.

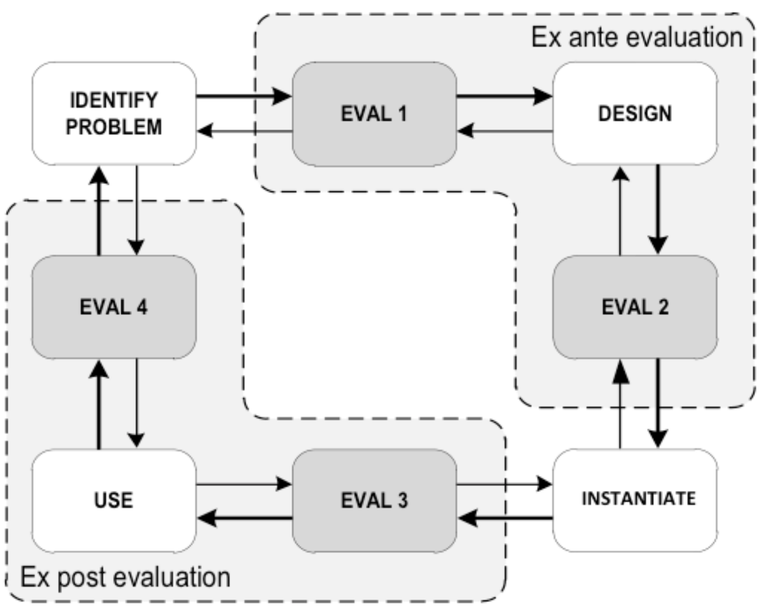

Figure 3: Evaluation Activities within the DSR Process (Adapted from Sonnenberg and vom Brocke (2012))

To demonstrate, Sonnenberg and vom Brocke (2012) identify four evaluation types (Eval 1 to Eval 4) derived from typical DSR activities. Figure 3 shows a cyclic high-level DSR process that includes the activities of problem identification, design, construction, and use. In addition, Figure 3 suggests that each DSR activity is followed by an evaluation activity, as follows:

- Eval 1: Evaluating the problem identification; criteria include importance, novelty, and feasibility
- Eval 2: Evaluating the solution design; criteria include simplicity, clarity, and consistency
- Eval 3: Evaluating the solution instantiation; criteria include ease of use, fidelity with real-world phenomena, and robustness
- Eval 4: Evaluating the solution in use; criteria include effectiveness, efficiency, and external consistency.

Depending on when an evaluation occurs, *ex ante* and *ex post* evaluations are distinguished. *Ex ante* evaluations are conducted before the instantiation of any artefacts, while *ex post* evaluations occur after the instantiation of any artefact (Venable, Pries-Heje, & Baskerville 2016). The DSR process in Figure 3 indicates that there are feedback loops from each evaluation activity to the preceding design activity. Overall, these feedback loops together form a feedback cycle that runs in the opposite direction to the DSR cycle.

Design Knowledge Framework

The design knowledge (DK) produced in a DSR project can be richly multifaceted. DK will include information about the important problem, the designed solution, and the evaluation evidence. Specifically it includes measures of timely progress on how well the problem solution satisfies the key stakeholders of a problem.

We consider these three components to constitute DK: the problem space, the solution space, and the evaluation. While we understand that both problem space knowledge and solution space knowledge exists independently, it is only through putting them in relation to one another that we refer to the respective knowledge as DK. Figure 4 provides a simple model conceptualizing important components of DK.

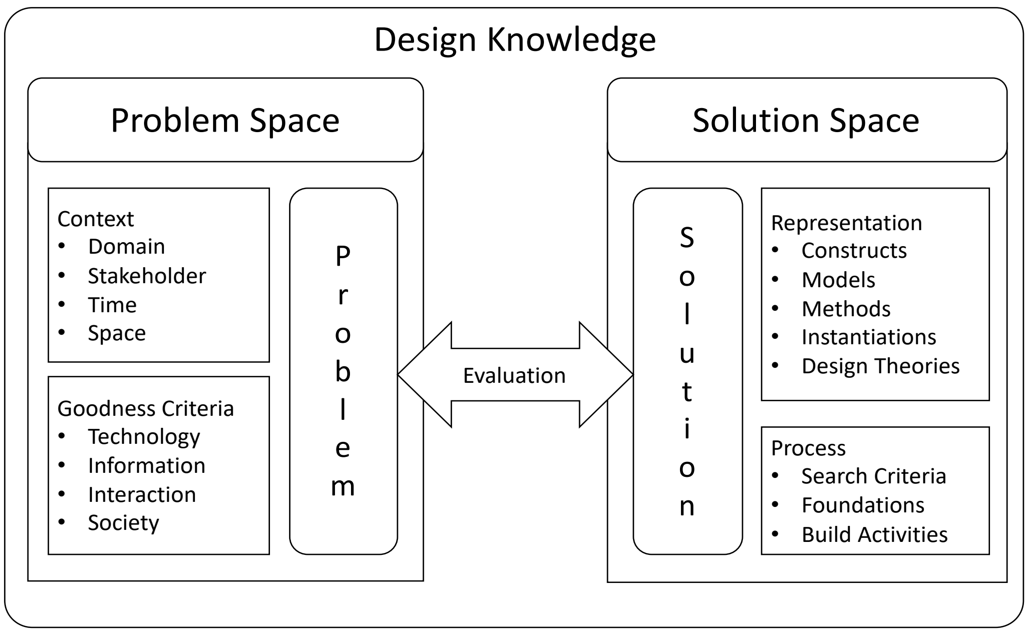

Figure 4: Components of Design Knowledge for a Specific DSR Project

Information systems research consumes and produces two basic types of knowledge: 1) behavioral science-oriented research activities primarily grow propositional knowledge or Ω-knowledge (comprising descriptive and explanatory knowledge), and, 2) DSR-oriented research activities primarily grow applicable (or prescriptive) knowledge or λ-knowledge (Gregor & Hevner 2013). Contributions to the λ knowledge base typically comprise knowledge about technological (i.e. digital) innovations that directly affect individuals, organizations, or society while also enabling the development of future innovations (Winter & Albani 2013). Contributions to the Ω knowledge base enhance our understanding of the world and the phenomena our technologies harness (or cause). Research projects may combine both paradigms of inquiry and contribute to both knowledge bases.

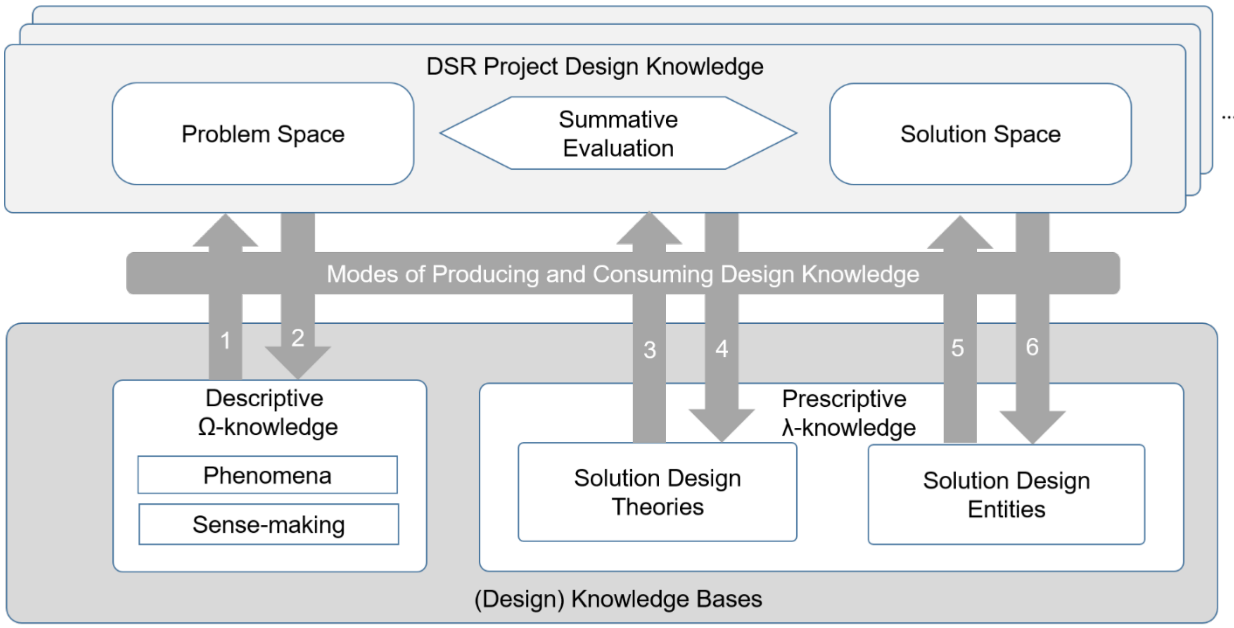

Figure 5: DSR Projects and Modes of Producing and Consuming Design Knowledge (Adapted from Drechsler & Hevner (2018))

The relationships of design knowledge produced and consumed in DSR projects and the (design) knowledge bases are shown in Figure 1. This figure is adapted and simplified from (Drechsler & Hevner 2018) and clearly illustrates paired modes of consuming and producing knowledge between the DSR project and the Ω and λ knowledge bases. The λ-knowledge is further divided into two sub-categories. The *Solution Design Entities* collect the prescriptive knowledge as represented in the tangible artifacts, systems, and processes designed and applied in the problem solution space. The growth of design theories around these solutions is captured in the *Solution Design Theories* knowledge base (Gregor & Hevner 2013). Knowledge can be projected from the specific application solutions into nascent theories around solution technologies, actions, systems, and design processes based on the new and interesting knowledge produced in a DSR project. Thus, we can describe the interactions of a specific DSR project with the extant knowledge bases in the following consuming and producing modes:

- Descriptive (Ω) Knowledge: Ω-knowledge (or kernel knowledge) informs the understanding of a problem, its context, and the underlying design of a solution entity (Arrow 1). As results of the research project, the design and real-world application of solution entities or design knowledge enhances our descriptive understanding of how the world works via the testing and building of new Ω-knowledge (Arrow 2).

- Prescriptive (λ) Solution Design Entities: Existing solution entities, design processes, or design systems are re-used to inform novel designs of new entities, processes, or systems (Arrow 5) (vom Brocke & Buddendick 2006). Within a DSR project, effective solution entities, design processes, or design systems are produced and contributed to new λ-knowledge (Arrow 6).

- Prescriptive (λ) Solution Design Theories: Solution design knowledge, in the form of growing design theories, informs the design of a solution entity, a design process or a design system (Arrow 3). Within a DSR project, effective principles, features, actions, or effects of a solution entity or a design process or system are generalized and codified in solution design knowledge (e.g. design theories or technological rules) (Arrow 4).

Three Types of Design Science Projects

In simple terms, a DSR project can make two types of contributions—it can contribute to design entities or to design theory—and conducting design processes in search of solutions to problems and theorizing about such processes are what lead to these contributions (vom Brocke, Maedche 2019). The two type of contributions and related activities are illustrated in Figure 6.

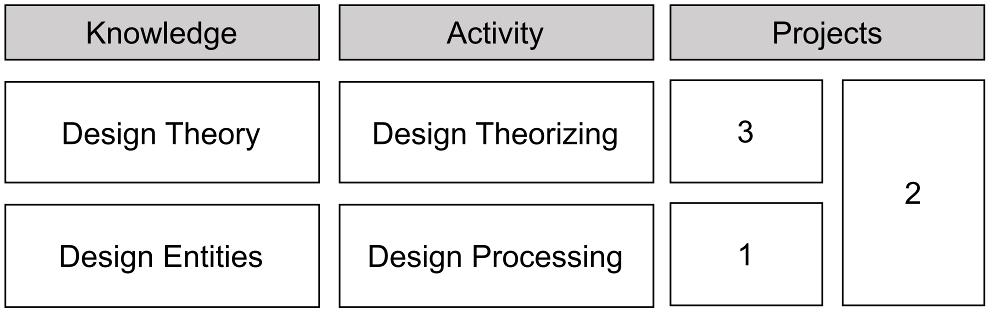

Figure 6: DSR Projects' Contributions to Design Knowledge

Early contributions to DSR focused on contributions to design entities (e.g., Hevner et al. 2004 and Peffers et al. 2007). Gregor and Jones (2007) introduce the idea of DSR projects' producing design theory and conceptualize the anatomy of a design theory by means of six core components: purpose and scope, constructs, principle of form and function, artifact mutability, testable propositions, and justificatory knowledge. Gregor and Hevner (2013) outline how both types of contributions relate to each another and how a DSR project can go beyond the design of design entities to contribute to design theory by theorizing about the design science process and the evaluation result achieved.

More recently, Chandra-Kruse, Seidel, & vom Brocke (2019) suggest a third type of DSR project that builds on design processes that are not conducted as part of the DSR project itself but at another place and time. Such research opens DSR projects up to theorize about design that is not motivated by research but by something that happened in, for example, industry or society. Drawing from archeology research, researchers have described methods for investigating design processes and artifacts empirically to generate DK. In short, three types of DSR projects can be differentiated regarding the contribution they intend to make to DK: (1) projects that contribute to design entities, (2) projects that contribute to both design entities and design theory, and (3) projects that contribute to design theory without developing a design entity as part of the same project.

Given the complexity of DSR projects and the various ways a DSR project might contribute to DK, how comprehensively and effectively a DSR project is planned and communicated can affect its likelihood of success. Such planning and communication enables researchers to reflect on and receive feedback about their DSR project in its early stages and to question and update their scope as they progress in the project.

The Design Science Research Grid

The DSR Grid (vom Brocke & Maedche 2019) enables researchers to effectively plan, coordinate and communicate their DSR projects. The DSR grid intends to put an entire DSR project on one page, highlighting its essential components in order to reflect and communicate its scope. Such representation of a DSR project helps to better plan and communicate a DSR project as well as to receive feedback from different stakeholders in an early stage and to question and update the scope as the project progresses. As shown in Figure 7, the DSR Grid consists of the six most important dimensions of a DSR project**.**

Problem Description: What is the problem for which a DSR project must identify possible solution? Problems should be formulated by means of problem statements and characterized by positioning the problem in a problem space. Research has identified the context, described by the domain, the stakeholder, time and place, and goodness criteria, the last of which tells when a problem should be considered solved, as necessary to capture the problem appropriately (vom Brocke et al. 2020).

Input Knowledge: What prior knowledge will be used in the DSR project? As introduced above one can distinguish Ω-knowledge and λ-knowledge, the first being descriptive, explanatory, or predictive, and the second being prescriptive (Gregor & Hevner 2013). Three types input — kernel theories, design theories, and design entities — can be differentiated for high-level communication about DSR projects.

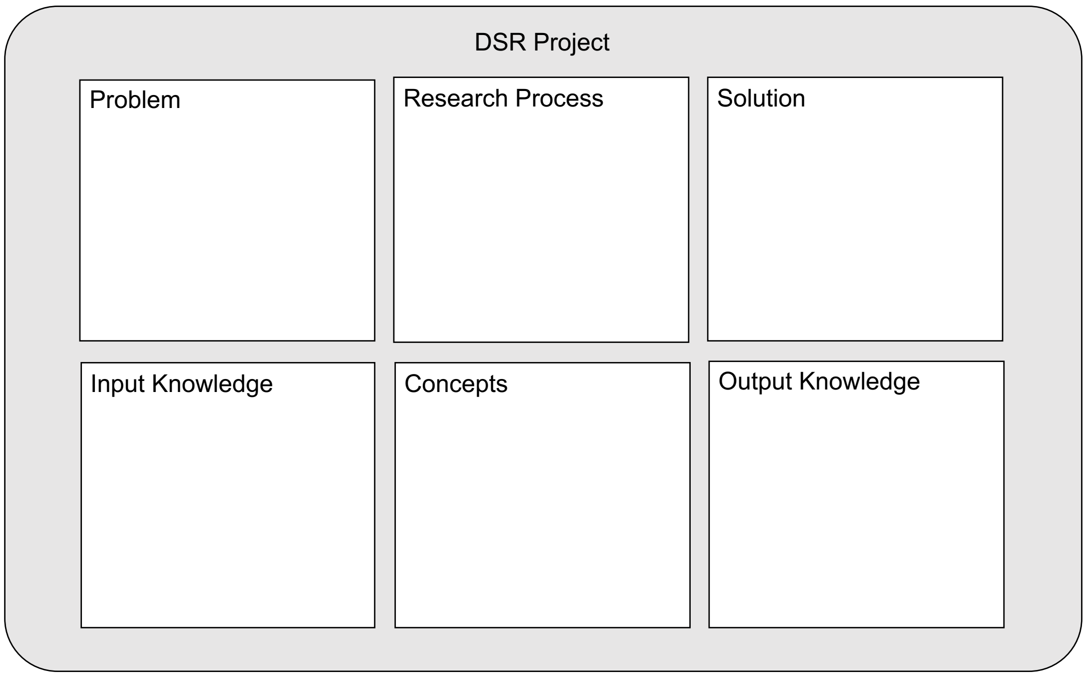

Figure 7: DSR Grid Comprised of the Six Core Dimensions of a DSR Project

Research Process: What are the essential activities planned (or conducted) to make the intended contribution? When the intended contribution is design entities, the process includes build and evaluate activities (Hevner et al. 2004). In particular, these activities also include grounding the design (vom Brocke et al. 2020) by, for example, conducting literature reviews (Webster & Watson 2002, vom Brocke et al. 2015), and meta-analysis (Denyer, Tranfield & Van Aken, 2008). In order to support concurrent design and evaluation, it is suggested to plan and document the build and evaluation activities in one. DSR tools have been developed (vom Brocke et al. 2017, Morana et al. 2018) to keep logs of the research process; such logs can complement a high-level list of research activities used to scope the DSR project in the process dimension. The process documented here may also include activities for theorizing about the design. While activities for processing the design can draw from DSR process models like the

Peffers et al. (2007) model, activities for theorizing can draw from various research methods and strategies of inquiry, such as qualitative and quantitative empirical research.

Key concepts: What are the most important concepts used in the research performed in the DSR project? The words used to describe the research, such as the problem and solution space that the DSR project focuses on, as well as the concepts used to describe the process and input and output knowledge must be defined clearly. A clear definition of the key concepts is particularly important to ensure a rigorous execution of the evaluation activities.

Solution Description: What is the solution to the problem being investigated by a DSR project? The solution description clearly states the essential mechanisms of the solution (vom Brocke et al. 2020) and how the solution is positioned in solution space by characterizing its representation as a construct, a model, a method, an instantiation, or a design theory.

Output Knowledge: What knowledge is produced in the DSR project? Naturally, DSR projects produce DK, classified as λ-knowledge (Gregor & Hevner 2013), but in contrast to the solution description, the DK generated through the project puts the problem and solution spaces in relation to each other (vom Brocke et al. 2020). If a DSR project does not intend to generate design theory but to generate design entities, the description of such entities does not constitute DK, as it is only the results of the design entity's evaluation in context that constitute DK. These results are then documented as output knowledge when the project is described.

Factors like the phase of the project (e.g., early planning or documenting completed research) and the stakeholder group (e.g., industry partners or editors) determine the perspectives from which and the detail with which the six dimensions may be described. Multiple versions of the dimensions will usually be created in iterations as a project progresses, but referring to the dimensions helps researchers to consider the core aspects of a DSR project from the outset and to discuss these aspects with stakeholder groups to shape the project`s profile further as it goes along.

Conclusion

In this chapter, some important DSR concepts and models have been presented to provide a foundation for the planning, performing, and disseminating DK from specific DSR projects. In the following chapters, cases of DSR projects are presented as conducted by experienced researchers in the field. These cases serve as examples from which to learn in order to inform one's DSR projects. These case studies provide invaluable experiential knowledge of how fellow researchers have conducted DSR over the past decades. This case collection is intended to "live" in that we are always very happy to include new cases of diverse application environments. The richer the collection, the more useful for the community. Apart from enjoying to read the cases in the book, authors are cordially invited to get in touch and discuss how to add their own case to this collection.

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