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Mixing Oil with Water: How to Effectively Teach Design Science in Management Education?

Duygu Keskin[1]
Georges Romme[1]

[1]Eindhoven University of Technology, Eindhoven, Netherlands

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Abstract

The methodology of design science (DS) has been emerging as a new form of engaged scholarship in which key managerial and organizational challenges are addressed and solved. These developments have major implications for management education, which has been repeatedly criticized for its lack of relevance to practitioners. However, design science methodology and its implications for management education are still unclear and disputed. Teaching and learning DS thus often suffers from the lack of a consistent methodology. In this respect, teaching DS is very much like mixing oil with water. The purpose of this paper is to compare various taxonomies for DS methodology proposed in the management literature and then develop a consistent taxonomy and integrative framework that may appeal to management students at undergraduate and graduate levels. The proposed framework for DS involves an iterative cycle of exploration, synthesis, creation and evaluation. Design principles arise from, but also connect and inform, these four steps in DS.

Keywords: design science; management education; methodology; integrative framework.

Introduction

In recent years, design approaches have been gaining attention and recognition in management discourse. In management practice, this has been promoted via the term *design thinking* (Brown, 2008; Kimbell, 2011; Liedtka, King, & Bennett, 2013; Martin, 2009). Boland and Collopy (2004) recommended that managers learn to think in the way designers think and approach business problems as the way designers address design problems. In a similar vein, design has been gaining recognition as a legitimate form of inquiry within management research (e.g. Hatchuel, 2001a; Romme, 2003; Van Aken, 2005). Design-oriented research has especially been proposed as a way to bridge the gap between theory (i.e. rigor) and practice (i.e. relevance), to produce scientific knowledge while solving complex and relevant field problems (Gibbons et al., 1994; Romme, 2003). In this respect, the methodology of *design science* (DS) has been emerging as a new form of engaged scholarship in which researchers and practitioners co-produce knowledge (Andriessen, 2007; Hatchuel, 2001b; Holmström, Ketokivi, & Hameri, 2009; Pascal, Thomas, & Romme, 2013; Romme & Endenburg, 2006).

These developments have major implications for management education, which has been repeatedly criticized for its lack of relevance to practitioners (e.g. Dunne & Martin, 2006; Romme, 2016; Simon, 1967; Van Aken, 2004). Some management and business schools are therefore seeking to include design research in their curriculum, to be able to better educate (future) managers who are equipped with design research competences, such as evidence-based problem solving, abductive reasoning, idealized design, and other research capabilities that enable a deeper understanding of users and their experiences (Ackoff, 1993; Dunne & Martin, 2006; Van Aken, Berends, & Van der Bij, 2012), and, in turn, can improve professional practice (Pascal et al., 2013).

Despite these developments, the idea of design and its implications for management education are still unclear and disputed. There is a diversity of concepts, such as design thinking (Brown, 2008; Martin, 2009), C-K theory (Hatchuel, 2001b), science-based design (Andriessen, 2007; Romme & Endenburg, 2006), design versus science (Banathy, 1996), which makes design and its potential for management education rather ambiguous and therefore difficult to exploit. In this respect, several authors have proposed taxonomies and frameworks to enhance the consistency of language and key terms used (e.g. Dresch, Lacerda, & Antunes, 2015; Romme & Reymen, 2018; Van Aken et al., 2012).

The purpose of this paper is to compare the various taxonomies for DS methodology proposed in the management literature and then develop a consistent taxonomy and framework that may appeal to management students at undergraduate and graduate levels. In this respect, the authors of this paper have been engaged in teaching courses in DS methodology for many years and have directly experienced how students suffer from the lack of a consistent methodology for DS. Moreover, as Simon (1967) already signaled, teaching an inclusive (DS-like) approach is very much like "mixing oil with water" (p. 16): that is, it is easy to provide the recipe on paper, but rather difficult to produce and sustain the mix.

We therefore seek to integrate the variety of concepts, to develop a comprehensive understanding of design science methodology that enables students to apply it in simultaneously solving real-life business problems and developing generalizable theoretical design knowledge from practical experiences and interventions. For this purpose, we review three frameworks for DS proposed in the literature, that is, those proposed by Van Aken (2004, 2005), Romme and others (Romme, 2003; Romme & Endenburg, 2006), and Holmström, Ketokivi and Hameri (2009). On the basis of our analysis, we subsequently propose an integrative framework that can facilitate teaching and learning DS. Although the discussion here is within the context of the management field, the presented framework may also be applicable in adjacent fields, such as industrial design, engineering, information systems, and others.

The argument is structured as follows. We, first, review the three DS frameworks. Subsequently, we present an integrative framework based on our analysis of the three existing frameworks. Finally, we reflect on how the proposed framework can facilitate teaching and learning DS in management and business schools.

Three Design Science Frameworks

In this section, we present the three DS frameworks and how they are applied in other empirical studies. This review sets the stage for developing the integrative framework for teaching purposes.

We selected the frameworks based on two sets of criteria: each framework should have had a major impact (i.e. be widely applied)[1] and offer straightforward guidelines for application. The frameworks were identified based on a search on Google Scholar for the most-cited publications on design science methodology in the management area. This process resulted in DS frameworks proposed by Van Aken (2004, 2005), Romme (2003), and Holmström et al. (2009).

Van Aken's framework

The first DS framework reviewed here is proposed by Van Aken (2004, 2005). Van Aken (2004) suggests that the relevance-rigor gap in management research can be mitigated by complementing description-driven research with prescription-driven research based on the paradigm of design science. The typical research products of this type of research would be scientific design knowledge in the form of "field-tested and grounded technological rules to be used as design exemplars of managerial problem solving" (Van Aken, 2004, p. 221). Technological rules are based on an intervention-outcome logic. That is, they link an intervention or artifact to a desired outcome in a certain field of application and can be represented in the form of a prescription, for example, "if you want to achieve Y in situation Z, then perform action X" (Van Aken, 2004, p. 227). Such a prescription applies to a limited scope of settings and is valid for a class of problems, which can then be used by other researchers and practitioners in similar projects and situations. A class of problem refers to problems that are experienced in different contexts but share common characteristics (Dresch et al., 2015).

With respect to the design science process, Van Aken (2004) makes a distinction between the problem-solving (i.e., regulative) cycle and the reflective cycle. The problem-solving cycle is concerned with a unique and specific business problem in practice. It consists of the following steps: problem definition, diagnosis, design of alternative solutions, selection, implementation and evaluation. It is followed by a reflection on the solution designed to distill a general solution concept, or technological rules, to be used for solving similar problems in other settings. The key question of the problem-solving cycle is pragmatic in nature: whether an intervention works or not.

The reflective cycle, on the other hand, is concerned with the field-testing of technological rules through the evaluation of interventions in the context of their intended use. The key question of the reflective cycle is to answer the question: what makes an intervention work? That is, it seeks to uncover the generative mechanisms that are likely to explain why an intervention produces a specific outcome. Testing an intervention in other settings is likely to result in adaptations in the intervention as well as in the preliminary technological rules distilled from problem-solving activities.

Van Aken's framework has been applied by, amongst others, Andriessen (2007), Birnik and Bowman (2007), Hellström, Tsvetkova, Gustafsson and Wikström (2015) and Holloway, Eijnatten, Romme and Demerouti (2016). An example is the work of Holloway et al. (2016), which draws on the problem-solving and reflective cycles to iteratively develop an intervention in a series of three studies. The authors engage in problem-solving and reflective cycles in each study to develop various versions of a value-crafting tool and corresponding theory. In the first study, they review the literature on work design and human resource management and collect data in an experimental research design, in which two different teams in a particular organization participate in a work-crafting intervention. The research methods used to collect data in this study are questionnaires, direct observations and focus-group interviews. In the second study, they focus on value crafting as a particular notion of work crafting to explore how it influences individual and team development. They review literature on complexity research and adopt a longitudinal and cross-sectional case study design to collect data on two research and development teams within the same organization. These teams are asked to use a value-crafting tool, an improved version of the initial intervention in the first study, prompted by a facilitator to follow a four-step process. Similar to the first study, the research methods used to collect data in this study are questionnaires, direct observations and focus-group interviews. Finally, in the third study, the authors explore self-guided crafting (i.e. without the involvement of a facilitator) and its potential effects. They collect longitudinal data in a diary study, in which participants are asked to write a diary on the way they value crafted whenever they deemed it appropriate. The research of Holloway et al. (2016) illustrates the use of various research methods in iteratively developing a value-crafting tool for a particular organization and a generic value-crafting theory applicable to any organization that is facing similar problems.

Romme's framework

The second framework we review is the science-based design approach proposed in Romme (2003) and further developed by Romme and Endenburg (2006). Romme (2003) proposed a framework for communication and collaboration between the science and design modes of research in the field of organization and management studies, arguing that a key element of the interface between science and design involves the notion of design propositions (which inform the development of solutions for particular management problems). Accordingly, design propositions are developed through testing in practical contexts as well as grounding in the empirical findings of organization science. Romme (2003) argued that this type of research would enable collaboration between the design and science mode, while it would also respect some of the methodological differences between the two modes. More specifically, he demonstrated how design propositions are redefined into hypotheses that can be empirically tested in the science mode, and vice versa, how hypotheses grounded in empirical evidence are translated into preliminary design propositions.

Romme and Endenburg (2006) further developed this approach to guide practitioner-academic projects in the form of a research cycle involving five components or steps: organization science, construction principles, design rules, organization design, and implementation and experimentation. Organization science refers to the body of knowledge that acts as the theoretical foundation for construction principles. This knowledge is represented in propositions that are descriptive in nature (i.e., given conditions C, if A occurs, then B is likely to follow). Construction principles are imperative propositions that are grounded in organization science and guide the process of (re)developing organization designs. They are prescriptive in nature and assert a certain type of solution in view of certain values or goals (i.e., to achieve A, do B). Design propositions (or design rules) are detailed guidelines for designing organizations and grounded in construction principles. They are, in a way, contextualized versions of construction principles. As such, they can be formulated as: if condition C is present, to achieve A, do B.

Organization design refers to the process of developing representation of the intended organizational design on the basis of the design rules. These representations might be in the form of drawings, models, narratives, and others. Via design, these representations as well the underlying principles and rules are further contextualized. While construction principles and design rules have a broader scope of applicability and, as such, cannot be directly tested in practice or in a particular context, organization designs are specific to the design situation and the preferences of the people engaging in the organizational design effort. Finally, implementation and experimentation refer to the iterative processes of testing the organization design, learning from the processes and outcomes caused by the design and adapting it to the emerging circumstances. The objective of this step is to find out whether the design, or which aspects of the design, works or not.

Although not mentioned as an explicit component, Romme and Endenburg (2006) refer to the analysis and interpretation of the processes and outcomes generated by the design and the reflection on existing organizational theories or the development of new ones, as the final step that completes the science-based design cycle.

While the initial conception of Romme and Endenburg (2006) puts theory first (i.e., organization science as the basis of design activities and solutions), Romme and colleagues have been showing that design principles can alternatively be derived in an emergent fashion through experimenting with new practices and solutions (e.g., Van Burg, Romme, Gilsing, & Reymen, 2008). This emergent approach is especially useful and valid when design principles are non-existent (e.g., because the field is immature), unknown to professionals (Van Burg et al., 2008), or when design goals are ambiguous, making it difficult to choose relevant bodies of work (Hodgkinson & Healey, 2008).

The framework proposed in Romme (2003) and Romme and Endenburg (2006) has been applied by, amongst others, Bevan, Robert, Bate, Maher and Wells (2007), Van Burg, Romme, Gilsing and Reymen (2008), Van Burg, Jager, Reymen and Cloodt (2012) and Pascal, Thomas and Romme (2013). For example, Van Burg et al. (2012) develop design principles for the corporate venture transition processes in established technology firms. This study combines a multiple-case study with a design science approach to develop a set of design principles for guiding managers in the corporate venturing process. Interviews are conducted with founders, managers and corporate management to explore the success, tensions, problems and progress of the ventures' transition processes. By analyzing the empirical data, they formulate a set of preliminary design principles, which are then further underpinned and refined by a review of entrepreneurship, strategic management and innovation management literatures. The final design principles suggest various actions and interventions that can be taken by managers in different stages of the corporate venturing process. This study illustrates how design knowledge can be developed on the basis of organizational practices and extant literature in an iterative but systematic way.

Holmström, Ketokivi and Hameri's framework

The third framework is the design science approach proposed by Holmström et al. (2009) for the field of operations management. According to these authors, the development of an artifact is what distinguishes design science from other research approaches, such as action research and participatory case studies. In DS, the objective is to develop "a means to an end" (Holmström et al., 2009, p. 67), that is, an artifact is designed to solve a problem. As such, the DS perspective developed by Holmström et al. (2009) is based on the analysis of the present state, desired state, and the design of actions that may help move from the present to the desired state. They suggest that either the means or the end, or both, must be novel. Accordingly, novelty is an important criterion for the evaluation of the artifact and the generalization of specific findings arising from a DS research project (Holmström et al., 2009).

Holmström et al. (2009) distinguish between four phases of DS research at a macro level, that is, the level of DS research community. The four phases are solution incubation, solution refinement, explanation I–substantive theory, and explanation II–formal theory. The solution incubation phase consists of framing the business problem and developing a preliminary solution design. A solution design is not yet complete, but is detailed enough to be evaluated and tested. This phase involves developing a synthesis of multiple disciplines and, as such, requires abductive reasoning in spotting the commonalities across different knowledge domains. From a means-end perspective, this phase requires the analysis and representations of present states (i.e. how is it today?) and desired state (i.e. how shall it be in the future?) and the actions that change the present states (i.e. how can existing tools be adapted or used in novel ways to solve the problem?).

In the solution refinement phase, the preliminary solution is refined through iterations and at the same time subjected to empirical testing in order to determine what works and what does not. This phase involves design improvements, implementation and evaluation. Implementation of the solution design in an empirical context is essential in this phase, since unintended consequences can be eliminated only via trial-and-error type of learning. From a means-ends perspective, this phase includes the documentation of satisfactory solution designs and the refinement of the solution to accommodate the idiosyncratic goals of different stakeholders in contexts other than the one where it was originally developed. The phase of solution refinement usually completes the process for practitioners, who are likely to stop when a satisfactory solution has been developed. The subsequent phases are therefore predominantly the domain of the design scientist, who seeks to generalize the findings and provide a scientific contribution.

In the substantive theory phase, the solution design is evaluated from a theoretical point of view to produce and advance a relevant theory. The substantive theory is context-dependent and has a limited scope of applicability, and as such, is not applicable across contexts. Since it is valid only in some type of context, arguments with respect to the contextual boundaries are an important part of the substantive theory. From a means-ends perspective, the objective of this phase is to generalize the research findings in a theoretical sense, through systematically implementing the solution in several contexts in which the means-ends proposition is relevant. In the phase of formal theory development, the DS scholar seeks to develop formal theory, which is not limited to the empirical context of the solution design initially developed, or specific type of organization or industry (Holmström et al., 2009).

Examples of empirical studies applying this framework are, amongst others, Hinkka and Tätilä (2013), Mastrogiacomo, Missonier and Bonazzi (2014), and Gylling Heikkilä, Jussila and Saarinen (2015). For instance, the study of Mastrogiacomo et al. (2014) illustrates the application of the framework proposed by Holmström et al. (2009). In this study, the authors build upon prior research on coordination in information systems project teams, and on Clark's (1996) joint activity theory, to improve real-time team coordination in information systems projects. They iteratively design and test a prescriptive framework and its instantiations in different phases of the framework proposed by Holmström et al. (2009). In the solution incubation phase, the authors combine the joint activity theory with their own project management expertise to develop a preliminary solution and test an alpha prototype in two organizations to solve everyday project management problems with real users. In the solution refinement phase, this solution is refined into a beta prototype and evaluated by a community of project management professionals. In substantive theory phase, the solution is further refined and tested in three real organizations as to its use and performance. The research methods used at this phase are interviews and project documentation, and an analysis of these through annotations, summaries and coding. In the formal theory phase, the authors reflect on the findings from the evaluation of the solution in its real use and present a new design theory for information systems research by extending the joint activity theory to fit information systems research. This study illustrates how extant theories can be combined with researchers' own management expertise (i.e., organizational practices) to iteratively develop a new design theory of project management in the field of information systems.

Table 1 provides an overview of the three DS frameworks discussed in this section.

Table 1

Characteristics of the proposed DS frameworks

	Van Aken (2004)	Romme and Endenburg (2006)	Holmström et al. (2009)
Research objectives	Uncovering generative mechanisms that make artifacts work (i.e., mechanism + context = outcome)	Produce knowledge that is actionable and open to validation	Develop a means to an end, i.e., an artifact to solve a problem: (a) explore new solution alternatives to solve problems, (b) explain this explorative process, (c) improve the problem-solving process
DS modes	Design mode: problem-solving cycle Science mode: reflective cycle	Design mode: development cycle Science mode: research cycle	Design mode: solution incubation, solution refinement Science mode: explanation I (substantive theory), explanation II (formal theory)
DS phases/ activities	Problem definition, diagnosis, design of alternative solutions, selection, implementation, evaluation, reflection on the effectiveness of technological rules	Organization science, construction principles, design rules, organization design, implementation and experimentation, analysis and interpretation	(a) Solution incubation: problem framing, solution design (finding a problem-solution pair) (b) Solution refinement: refinement through iterative testing in empirical context, implementation, evaluation (c) Substantive theory: evaluation of the artifact from theoretical point of view (d) Formal theory: generalizability of the results across contexts
Evaluation logic	Intervention-outcome (i.e., testing in context)	Experimentation and learning with respect to construction principles, design rules, and conditions for applying these rules	Means-ends analysis (i.e., the difference between present states and desired states, and actions that change the present situations)
Research products	Knowledge for the design and realization of artifacts Mid-range theories valid for a certain application domain	Actionable knowledge open to validation (i.e., knowledge in the service of action, directed toward desired situations)	Substantive theory of mid-range variety Formal theory
Design knowledge representation	Tested and grounded technological rules	Construction principles and design rules	Means-ends propositions

Proposal for an Integrative DS Framework

The three frameworks reviewed have similarities and differences in terms of terminology with respect to both the products and processes of design science. In this section, we synthesize these similarities and differences into an integrative framework that is applicable at the micro level of single research projects.

First, the typical design knowledge, or research products, arising from DS are prescriptions that can be formulated and represented in various formats. Second, although there are differences in the frameworks in terms of process steps suggested, the steps of analysis, design and evaluation appear to be crucial in a DS cycle. Finally, the role and use of science, as input or inspiration for the design effort, appears to be different and contingent on the level of maturity of the research effort. These three dimensions are elaborated further in the following subsections.

Design principles

The frameworks presented in the previous section suggest that the output of design science, that is design knowledge, can be represented in different forms: for example, means-end propositions (Holmström et al., 2009), field-tested and grounded technological rules (Van Aken, 2004) or design propositions/rules (Romme, 2003; Romme & Endenburg, 2006). We will here adopt the term *design principle* for representing design knowledge and further elaborate on its components. The notion of design principle thus serves to avoid the ambiguity arising from using different terms for the same purpose.

Despite the variety in terminology and form, the three frameworks suggest that the prevailing mode of thinking in design science is prescriptive in nature. This prescriptive knowledge usually defines an agency, that is, an actor and its actions (A), which trigger a particular mechanism (M) toward achieving a desired outcome (O) in a particular context (C). This knowledge is "not a specific prescription for a specific situation, but a general prescription for a class of problems" (Van Aken, 2004, p. 228). In other words, it is a mid-range theory of practice that has a limited scope of application and is valid in a particular problematic *context* (Holmström et al., 2009; Van Aken, 2004), that is, for a particular class of problems. A class of problems refers to problems that are experienced in different contexts but share common characteristics (Dresch et al., 2015). Therefore, design knowledge is valid for a class of problems and can be used by other researchers and practitioners in solving similar types of problems. In this context, an *action* refers to a particular act or process at the disposal of *actors* to influence behavior or achieve a particular outcome, such as leadership style, training and performance management (Denyer, Tranfield, & Van Aken, 2008).

An *outcome* refers to a desired future state that one seeks to achieve through a particular action (Denyer et al., 2008; Holmström et al., 2009; Van Burg & Romme, 2014). The key knowledge question in DS research is not so much whether an action achieves a particular type of outcome, but what are the associated mechanisms that make an action achieve that outcome in a certain context (Van Aken, 2004; Van Burg & Romme, 2014). A *mechanism* is a construct that explains why a particular outcome (pattern) is produced or generated in a certain context (cf. Gross, 2009; Van Burg & Romme, 2014).

In conclusion, design principles "involve a coherent set of normative ideas and propositions, grounded in research, which serve to design and construct detailed solutions" (Van Burg et al., 2008, p. 116). They have a central function in linking the science and design domain, as they are both the input for and output of design science research. On one hand, they function as design aids for developing general solutions for a class of problems (i.e., mental artifacts such as models and frameworks) and their particular instantiations (i.e., particular applications of mental artifacts for specific situations) (March & Smith, 1995; Romme, 2016) for solving practical problems and shaping practices (Romme, 2016). As such, they offer suggestions and guidelines, in the form of proposed actions and agencies, for incrementally or radically moving from a (problematic) present state toward a desired state. On the other hand, through observing, studying and testing the artifacts designed, as well as codifying the underlying design principles, DS contributes to the knowledge base of organization and management research (Van Burg, Jager, Reymen, & Cloodt, 2012). Design principles therefore appear to be at the heart of research efforts informed by DS.

Design science research cycle

After presenting the main characteristics and functions of design knowledge, we now turn to the main activities in a basic DS research cycle. The three frameworks presented in second section entail a combination of design and research activities, involving exploration of the problem context, synthesis of findings and existing theories, creation of artifacts, pragmatic and theoretical evaluation of these artifacts, and generalization of knowledge. Figure 1 provides an overview of our synthesis of the existing frameworks.

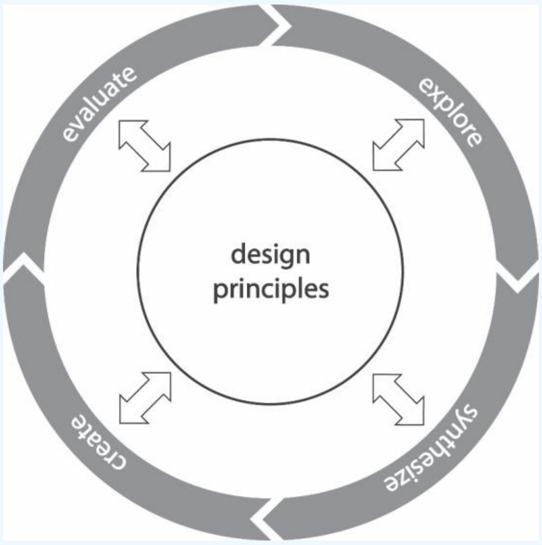

Figure 1. Generic DS cycle

At the heart of the framework in Figure 1 is the notion of design principles, which are created, adapted, acted and reflected upon throughout the DS research process. This process is highly iterative in nature, involving four steps: exploration, synthesis, creation and evaluation. Each step tends to emphasize different components of the design principles, that is, the class of problems, actions, outcomes and mechanisms involved. Each step may also imply a distinct combination of design and research methods. In this section, we will further elaborate on the DS cycle. Figure 2 presents an overview of methods and tools often used in DS projects, to illustrate how a generic DS process model can integrate and enable the use of a variety of research and design methods. As such, there is no single path for conducting design science in Figures 1 and 2. Rather, there appear to be an almost infinite number of combinations and sequences of DS steps and research methods.

The first step in a DS research cycle is *exploration*, which is about drawing the boundaries of the problem space. The goal of this step is to create an in-depth understanding of a perceived business problem or opportunity in its context and define a broader class of problems that represents this specific business problem/opportunity. The main question in this step is: what is going on here? As such, this step involves information gathering about people and systems (e.g., organizational and technical) through literature review and field research. For the exploration of the problem, a literature review can be used with a focus on identifying the causes of a particular class of problems/contexts, as well as the challenges, barriers and opportunities previously identified for this class. A literature review, in particular a systematic one (Denyer et al., 2008; Tranfield, Denyer, & Smart, 2003), can also be used to explore theoretical perspectives as well as potential generic solutions (i.e., meta-artifacts) and their underlying mechanisms, which may be instrumental in solving the problem and achieving the desired outcomes.

Field research can be conducted to understand the particular situation as it is, especially to understand what people do and why they do it. Field research also serves to explore solutions already existing in practice, identify best practices, and requirements and wishes of problem owners with respect to the desired situation. Ethnography, grounded theory and case study are examples of research approaches that can be adopted in this step. Research methods used in the exploration step often involve a combination of qualitative and quantitative methods, such as observations, user/expert interviews, surveys and focus groups.

Synthesis is about creating insights through inductive and abductive sensemaking in order to identify and forge connections and create a mental model of the design space (Kolko, 2010). The main question here is: how could it be? The previous step usually yields a vast amount of information in the form of scientific articles and empirical data. Reduction and synthesis of this information into meaningful and actionable chunks through inductive as well as abductive sensemaking is the main activity in the synthesis step, to enable the formulation of design requirements and design principles. The data collected and analyzed regarding the four CAMO dimensions are synthesized into design principles, which are used as design aids for creating generic artifacts and their particular instantiations (Hodgkinson & Healey, 2008).

Design principles can be formulated by using the CAMO logic developed by Denyer, Tranfield and Van Aken (2008) or the similar CMO format proposed by Van Burg and Romme (2014). This type of format covers the various dimensions of design principles, that is, it defines the contextual class of problems in which a particular mechanism is evoked by introducing a particular action, in order to increase the likelihood that intended outcomes are accomplished. In addition, affinity diagrams, flow diagrams, and scenarios are design tools that can be used to make sense of the empirical data and formulate design requirements (Kolko, 2010), and guide the formulation of design principles. More conventional qualitative data analysis techniques can also be used to infer and formulate design requirements and principles. Design requirements define the expected outcomes and desired states in practice, and in turn, help in scoping the design principles.

The third step, *creation*, is about shaping and developing artifacts (i.e., generic and/or particular solutions) to the problem (class) and achieving the desired outcomes defined in the previous steps. The main question in this step is: how should it be tomorrow? The creation step mainly involves activities such as ideation, conceptualization, visualization and prototyping. There is a vast amount of design tools in the product, engineering and software design literatures; for example, brainstorming and system mapping can be used for ideation and visualization, and analysis of morphological parameters can be used for detailing a selected solution.

Finally, *evaluation* refers to the assessment of the pragmatic value of the solution and the theoretical reflection on findings from the DS project. From a pragmatic point of view, the main question is: does the designed solution work? For example, the solution can be evaluated in terms of its functionality, completeness, consistency, performance, usability, fairness, and fit with the organization (Hevner, March, Park, & Sam, 2004). From a theoretical point of view, the goal of this step if to demonstrate the theoretical relevance of the solution and identify the mechanisms that explain how the solution generates the desired outcomes. The main question of theoretical reflection is: why does the solution work? A deep reflection effort on the findings arising from the creation step needs to draw on extant theories and preliminary design principles (developed in the synthesis stage), which in turn is likely to result in revising the initial design principles as well as formulating entirely new ones.

In this step, CAMO logic can also be used to compare and synthesize the findings arising from the DS cycle with alternative theoretical perspectives (Pascal et al., 2013; Van Burg et al., 2008). Moreover, the generalization process proposed by Holmström et al. (2009), involving two levels of explanation in terms of substantive and formal theory, can be very helpful here. Another useful approach can be the evaluation framework proposed by Venable, Pries-Heje and Baskerville (2016), which offers suggestions for why, when, how and what to evaluate in design science research project. The main activities in the evaluation step are testing and evaluating solutions. The solutions can be evaluated by means of artificial evaluation via, for example, computer simulations, role-playing simulations, field and lab experiments, and naturalistic evaluation via case studies, survey studies, field studies and action research (Iivari & Venable, 2009). Other research methods often used are focus groups, scenarios, expert/user interviews.

Figure 2 provides an overview of a number of methods and tools that are often used in DS research. This figure thus illustrates the variety of methods and tools which can be adopted. There is not a concrete boundary between the phases of the cycle, thus some of the methods can be used during the different phases. We will not further discuss each of the methods and tools here.

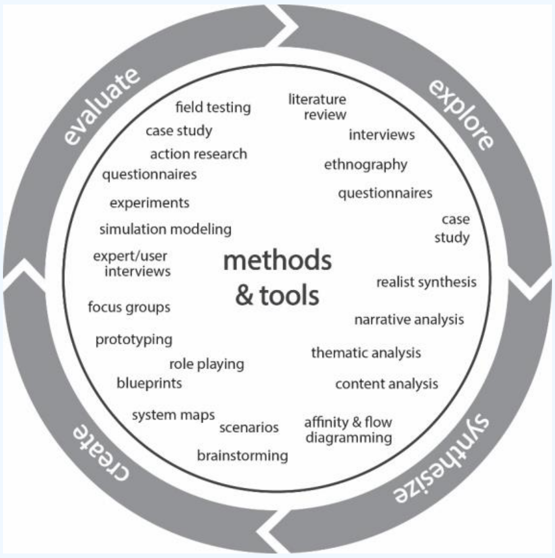

Figure 2. Methods and tools often used in DS

DS research strategies

In the previous subsection, we presented a four-step generic DS research cycle. This generic process is likely to look different across various DS projects, depending on the context of the research project, the research topic, and the researchers carrying out the project. In this respect, two broad DS research strategies can be distinguished, which are likely to require different approaches. The two broad strategies outlined in Table 2 arise from two distinct design perspectives: the perspective of rational problem solving proposed by Simon (1973) and the perspective of reflective practice proposed by Schön (1983) which was further developed by Dorst (2006). In this section, we discuss these two strategies.

Table 2

A comparison of the two DS research strategies

	Theory-driven DS	**Practice-driven DS**
Initial problem:	Can be defined rather well	Cannot be defined (yet)
Role of theory/design:	Theory first	Design first
Level of uncertainty:	Low	High
Iterations:	Moderate number of iterations	Very large number of iterations
Generalization:	High potential for generalization	Lower potential for generalization

The first strategy arises from the logic of rational problem solving. Accordingly, the design process starts with defining the problem through objective analysis and reframing, which is then followed by a search for a satisfactory solution. This strategy is also implicit in the original conception of DS methodology on the premise of evidence-based management: for example, Tranfield, Denyer and Smart (2003, p. 207) used the term “evidence-informed management” and Van Aken and Romme (2009, p. 9) referred to “theory-informed business problem-solving”. Accordingly, we call this the strategy of *theory-driven DS*. A researcher using this strategy starts by analyzing and reframing a perceived business problem, which is likely to lead to a number of potential theoretical perspectives that can be used as guidelines for the design process. S(he) then conducts a systematic literature review of the existing knowledge-base with regard to the theoretical perspective chosen for design, accordingly formulates design principles, and develops a general solution concept (Van Aken & Romme, 2009) or a meta-artifact (Hevner, 2007), which is subsequently instantiated into a specific solution concept (Van Aken, 2004) to be implemented in a specific business context.

This strategy is especially appropriate in more mature knowledge domains (e.g. Meulman, Reymen, Podoynitsyna, & Romme, 2018; Pascal et al., 2013), where there is sufficient empirical evidence with respect to a portfolio of potential solutions; and preferably this knowledge is also available in the form of design principles or similar kinds of design knowledge. For example, in case of a clear problem with unambiguous goals and an easily identifiable class of problems, a theory-driven approach can be adopted, in which the literature is reviewed, design principles are formulated, and a solution is developed and tested. The development of design principles and artifacts is thus primarily driven by extant theories, which are subsequently evaluated in practice via specific solution concepts. On the basis of this evaluation, the design principles and meta-artifacts can be adapted and, as such, existing theories are confirmed, extended or refuted. The research products of this strategy are likely to be more generalizable, as they start from theories and empirical evidence in previous studies. In the theory-driven DS approach, specific solution concepts can thus be viewed as hypotheses, which enable the evaluation of meta-artifacts from a theoretical point of view. Since there already is a lot of knowledge available, to be used as input for the various DS steps, the uncertainty and unambiguity of the DS project is considered to be low.

The second strategy arises from the discourse on reflective practice, conceptualized as “situated problem solving” (Dorst, 2006, p. 11). In this view, there is not a clearly defined problem to start with; design is conceived as a situated activity that requires the prioritization of the local design problem (that one faces) over any abstract problem (Dorst, 2003). That is, design problems do not exist as an objective reality; they are design situations viewed through the eyes of the designer, involving subjective design actions and decisions (Dorst, 2006). In this view, the DS cycle is conceptualized as the coevolution of problem and solution, implying a gradual and emergent process driven by experimentation and prototyping (Van Burg et al., 2008). As such, it requires a “constant iteration of analysis, synthesis, and evaluation processes” (Dorst, 2006, p. 10). We call this the strategy of practice-driven DS. It starts with creating a concrete solution to solve a particular business problem, driven by a process of reflection-in-action (Schön, 1983). This solution emerges from the deliberate process of engaging in multiple experiments, reflecting on their outcomes, and learning from those before deciding on subsequent steps. These learnings are then used to extract knowledge in the form of meta-artifacts and design principles, possibly after testing in other contexts.

The practice-driven strategy appears to be especially valid in emerging knowledge domains, where empirical evidence has not sufficiently accumulated and design knowledge is underdeveloped or even non-existent (Van Burg et al., 2008). In this respect, the novelty to be addressed can arise from a largely unknown context, set of mechanisms, and/or outcomes (cf. Holmström, Främling, & Ala-Risku, 2010). For example, if the DS project is concerned with an entirely novel organizational practice to be created (i.e., outcome), then existing theories might be consulted and used as theoretical input (i.e., mechanisms) for understanding this phenomenon. However, if there is no suitable theory available, one can adopt an entirely inductive approach with “a clean theoretical slate” (Eisenhardt, 1989, p. 536) such as the grounded theory methodology (Beck, Weber, & Gregory, 2013).

This type of DS research therefore is essentially geared towards theory-building. That is, the development of design principles and artifacts is primarily driven by current practices in organizations and the insights emerging from the actions initially designed and tested. Moreover, this strategy generates an initial body of empirical evidence and an initial set of design principles, which in turn drives the experimentation, evaluation and generalization in other cases and contexts. As such, the generalizability of the results of the practice-driven strategy tends to be limited. And because the available knowledge to inform the DS effort is limited or highly ambiguous, the level of uncertainty in such DS projects is rather high. As such, the DS process arising from a practice-driven strategy is likely to involve a substantially larger number of iterations through the cycle in Figure 1 than the process implied by its theory-driven counterpart.

Notably, the two strategies in Table 2 are not mutually exclusive. They represent the two ends of a single continuum, and thus most research is likely to fall in-between these two extremes and have characteristics of both approaches in varying degrees. As we have also argued earlier, there is not a single route to doing DS research. It is therefore important to contextualize the generic model in Figure 1 into a tailor-made *DS process approach* that fits the needs and goals of the particular project (e.g. Dresch et al., 2015; Pascal et al., 2013; Van Burg et al., 2008). Dresch, Lacerda and Antunes (2015, p. 27) use the term “work method” to refer to the organization and sequence of activities that will be followed in a particular project, including the methods and tools that will be used in it.

One should also keep in mind that each of the two strategies has its unique strengths and weaknesses. Starting the DS process on the basis of organizational practices is likely to result in more relevant results for practice, but runs the risk of separating practice from theory (Hodgkinson & Healey, 2008). On the other hand, starting the DS cycle with organizational theories is likely to result in more rigorous and generalizable theoretical results, but might demotivate creative choices when the theoretical perspective is not novel enough (Dorst, 2006; Dunbar & Starbuck, 2006; Hodgkinson & Healey, 2008). Finally, DS researchers themselves are an important factor in how the DS process evolves, as they have the freedom to follow their preferences in the way they reframe problems and create and assess solutions (Dorst, 2003; Holmström et al., 2009).

Concluding Remarks

A variety of DS methodologies and frameworks have been proposed, which has made design science and its potential for management education highly ambiguous and largely unexploited. Our purpose in this paper was to overcome this challenge by proposing a consistent taxonomy and framework, based on a comparison between three influential DS frameworks in the field of management.

In doing so, we proposed a generic process framework that can have an integrative and enabling function. The framework outlined in Figure 1 entails four key steps and enables the use of various methods and tools under the umbrella of DS. It also provides a standard regarding terms used for design knowledge and DS process activities. In Annex, we present a glossary of terms used in this framework, to decrease the confusion and increase the level of comprehension among students. It is often very challenging for students to intuitively grasp the various DS terms and concepts by reading materials and attending lectures. The framework and glossary are likely to help students in identifying and acquiring the vocabulary of DS, and in turn, navigating the landscape of the DS literature. However, a key challenge for teaching and learning DS remains, as there are many choices to make and paths to take in the actual application of any generic DS framework to a particular problem or challenge.

Note

[1] A search on Google Scholar on September 8, 2019 resulted in: 1472, 686 and 376 citations for Van Aken (2004), Romme (2003) and Holmström et al. (2009) respectively.

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Author contributions

1st author: conceptualization (equal), formal analysis (equal), methodology (equal), visualization (lead), writing-original draft (lead), writing-review and editing (equal).
2nd author: conceptualization (equal), formal analysis (equal), methodology (equal), supervision (equal), visualization (supporting), writing-original draft (supporting), writing-review and editing (equal).

Authors

Duygu Keskin
Eindhoven University of Technology, Department of Industrial Engineering and Innovation Sciences
Groene Loper 3, 5612 AE, Eindhoven, Netherlands
d.keskin@tue.nl
https://orcid.org/0000-0001-6330-4835

Georges Romme
Eindhoven University of Technology, Department of Industrial Engineering and Innovation Sciences
Groene Loper 3, 5612 AE, Eindhoven, Netherlands
a.g.l.romme@tue.nl
https://orcid.org/0000-0002-8513-7174

ANNEX

Glossary of terms for DS

Agency	A human actor and its action(s). An actor can be an individual or a group of individuals.
Artifact	A designed solution for a business problem. An artifact covers both general solutions for a class of problems (i.e. mental artifacts, such as models and frameworks) and their particular instantiations (i.e. particular applications of mental artifacts for specific business situations).
Generic DS cycle	A generic process model for carrying out design science projects.
Class of problems	Business problems that are experienced in different contexts, but share common characteristics (Dresch et al., 2015).
Creation	The activity of designing and developing generic and/or particular artifacts to solve a business problem and achieve the desired outcomes defined.
Design Science Methodology	Methodology that aims to link science and design through the development of design knowledge, to be used for creating artifacts.
Design principle	Prescriptive design proposition (or rule), grounded in research evidence, that serves to create and assess artifacts as well as generalize these artifacts in knowledge that is more broadly applicable. Design principles can be formulated using CAMO logic (Denyer et al., 2008).
DS process approach	Definition of the organization and sequence of activities followed, and the methods and tools used to design and develop an artifact in a particular DS project.
Evaluation	The activity of assessing the value of the artifact from a pragmatic and theoretical point of view. Evaluation typically involves defining the criteria for assessing the artifact and identifying mechanisms that explain why and how it generates the intended outcomes.
Exploration	The activity of creating an in-depth understanding of a perceived business problem or opportunity in its context, and to define a generic class of problems that represents the specific business problem or opportunity.
Mechanism	A theoretical construct that explains why a particular agency (i.e. actor and its action) in a specific context leads to a particular outcome (pattern).
Outcome	A desired future state that an actor seeks to achieve through a particular action (Denyer et al., 2008; Holmström et al., 2009; Van Burg and Romme, 2014). It also defines the boundaries of the desired future state.
Synthesis	The activity of creating insights through abductive sensemaking in order to identify and forge connections and create a mental model of the design space (Kolko, 2010). Synthesis typically also involves the formulation of design principles and design requirements, which inform the creation of artifacts.