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Construction of Design Science Research Questions

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Abstract:

Posing research questions is a fundamental step to guide and direct knowledge development in research. In design science research (DSR), research questions are important to define the scope and the modes of inquiry, characterize the artifacts, and communicate the contributions. Despite the importance of research questions, there are few guidelines on how to construct suitable DSR research questions. We fill this gap by exploring ways of constructing DSR research questions and analyzing the research questions in a sample of 104 DSR publications. The results show that about two thirds of the analyzed DSR publications actually use research questions to link their problem statements to research approaches and that most of the questions are aimed at problem-solving. Based on our analysis, we derive a typology of DSR question formulation to provide guidelines and patterns that help researchers formulate research questions during their DSR projects' duration.

Keywords: Design science research, Research question, Research question formulation, Research question construction

1 Introduction

Design science research (DSR) has become a popular and distinctive research paradigm in the information systems (IS) discipline. Major IS journals, such as MISQ, JAIS, BISE, and CAIS, have not only accepted DSR papers, but also dedicated several special issues to the paradigm (March & Storey, 2008; vom Brocke, Hevner, & Maedche, 2017; vom Brocke, Hevner, Maedche, & Winter, 2017). Furthermore, many researchers have adopted DSR to investigate a wide range of topics, such as decision support systems, management strategies, modelling tools, health care systems, and computational models and algorithms (Goes, 2014; Rai, 2017). In particular, about 80% of research related to decision support systems has applied DSR (Arnott & Pervan, 2012).

With its focus on artifact development, utility, innovation, and iteration, DSR contributes a distinctive paradigmatic approach to research, complementing other ways of doing science, such as the behavioral sciences. In particular, DSR helps develop innovative and useful artifacts, while behavioral science helps ascertain the truth in order to understand a certain phenomenon (Hevner, March, Park, & Ram, 2004; Niederman & March, 2012). DSR's distinctive approach includes specific methodological concerns and knowledge contribution types requiring special attention to constructing suitable research questions.

Constructing clear research questions is a fundamental step in any research study, because they indicate what the study is about and convey its essence (Dubé & Paré, 2003; Hassan, 2017; Venkatesh, Brown, & Bala, 2013). Several disciplines across the behavioral and the natural sciences have illustrated this fundamental role (Creswell, 2009; Hällgren, 2012; Miles, Huberman, & Saldaña, 2014), while numerous authors, including Recker (2012), Sandberg and Alvesson (2013), and Bryman (2015), have provided helpful advice for constructing research questions. Here, the question arises how DSR's distinctive nature should be reflected in suitable DSR research questions. Consider, for instance, the following three examples:

- In the behavioral sciences, research questions are often linked to explaining phenomena through causal relationships, usually expressed in the form "does X cause Y?" Can we adopt this type of question in DSR? A good fit seems hardly probable, because DSR builds innovative, useful (classes of) artifacts for specific (classes of) contexts with concerns for feasibility and improvement, but not for statistical generalizability (Mettler, Eurich, & Winter, 2014).
- In the natural sciences (e.g. physics and biology), research questions often concern how and why things are in order to identify natural laws pertaining to reality (March & Smith, 1995). When constructing and approaching these kinds of questions, a key principle is that the researchers and research objects are independent. For example, electrons are separate from the physicists who observe them (Weber, 2004). In DSR, however, applying this principle seems impractical, if not impossible, since research objects are the design artifacts that researchers construct deliberately.
- DSR-specific research questions often concern the development of artifacts ("how can we develop X?" or "how can we develop X to resolve Y?"). However, this type of question leads to conjectures that are hard to falsify. That is, the questions are not about a phenomenon that can be tested as either true or false, but about a phenomenon necessarily leading to a positive outcome. The latter occurs, because artifacts can be repeatedly developed and evaluated until the researcher achieves positive results.

In spite of these challenges, we fundamentally agree with Gregor and Hevner (2013): Clear research questions are necessary to present DSR's maximum impact, because they open up the problem and solution space for DSR to improve the current artifacts and develop new ones. We also agree with Hevner and Chatterjee (2010), who consider the research question the most important item on their DSR checklist. However, little guidance has been provided on how to construct DSR questions. Prior research focused on the general principles guiding DSR (Hevner et al., 2004), on broad views of the research process (Hevner & Chatterjee, 2010; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007), and on ethical issues regarding the responsibilities of researchers conducting DSR (Myers & Venable, 2014). The difficulties that the lack of guidance causes, may arise from a combination of multiple factors: the DSR paradigm's relative recentness, DSR's diversity, and the different contributions to knowledge generating design products and design processes (Gregor & Hevner, 2013; Rai, 2017). Based on the identified gap, we address the following research question:

RQ: How can we construct research questions in line with the DSR paradigm's nature and purpose?

By addressing this research question, we make three contributions: First, we identify and analyze the main arguments for constructing DSR research questions as expressed in the core literature. This analysis is based on a review of 104 publications from different outlets that explicitly state that they follow the DSR paradigm. Second, we propose and discuss a typology for formulating DSR research questions based on a synthesis of current practices. The synthesis examines common ways and patterns of formulating DSR research questions. Based on this foundation, we provide researchers with guidelines on constructing and formulating research questions that fit the DSR paradigm. Please note that we do not regard our guidelines as mandatory. Instead, we hope to inspire DSR researchers to construct, formulate, and reformulate suitable research questions throughout their research process and during the associated rigor, design, and relevance cycles to guide their inquiry. Finally, we highlight that the DSR paradigm has unique ways of constructing suitable research questions, which contribute to positioning it as a distinctive research paradigm.

We structure the paper as follows: In Section 2, we review the role of research questions in the IS discipline in general and in DSR in particular. In Section 3, we develop an analytical framework for our DSR publication analysis. In Section 4, we describe the literature review method adopted in this study. Section 5 presents the analysis results and findings from the review, while Section 6 shows in detail how DSR constructs research questions. In Section 7, we propose a typology for formulating DSR research questions. In Section 8, we discuss the findings and their implications. Finally, we conclude the paper and discuss future work in Section 9.

2 The Role of Research Questions

Research questions play a key role in academic research. Researchers use research questions to represent what their study addresses, investigates, and, ultimately, answers. Research methodology textbooks repeatedly highlight research questions' importance, emphasizing that they should be carefully defined (Creswell, 2009; Recker, 2012). Recker (2012), for instance, notes that "a research question should be a key statement that identifies the phenomenon to be studied. The research question(s) is/are the fundamental cornerstone around which your whole [doctoral] research revolves and evolves" (p. 27). Alvesson and Sandberg (2013) maintain that "without posing questions it is not possible to develop our knowledge about a particular subject" (p. 11). In other words, research questions are the required starting point for knowledge development in academic research.

In the IS discipline, we identify research questions' three key roles: 1) defining the research scope, 2) guiding the research process, and 3) positioning the contributions. The first role narrows the research focus from broad statements to specific questions to be answered. Supporting this argument, Creswell (2009) suggests that research questions make the type of research (e.g. qualitative, qualitative, mixed) more explicit and shape its boundaries. Research questions should also represent the researchers' investigative direction, therefore delimiting the perimeter of analysis (Bryman, 2007). In a similar vein, Miles et al. (2014) and Dubé and Paré (2003) suggest using research questions to define an IS study's focus.

Second, research questions frame the research process decisions, which specifically include the key decision about which method to use. The research questions guide researchers to choose "the most appropriate course of study that could be undertaken in order to answer the question[s]" (Recker, 2012, p. 31). Case study methods are, for example, largely suitable to address 'why' and 'how' types of questions (Benbasat, Goldstein, & Mead, 1987). Järvinen (2008) goes a step further and proposes a taxonomy that, given their formulated research questions, IS researchers can use to choose suitable research methods. In addition, many researchers use research questions to guide their research design, including the data collection and analysis, all of which are ultimately aimed at answering the initially formulated questions.

Third, research questions allow us to position the research contributions. Alvesson and Sandberg (2013) suggest that the ultimate reason for answering research questions is to contribute to the human knowledge base by either bridging a knowledge gap in the literature or producing original knowledge. Research questions also allow us to communicate the research contributions (Rosemann & Vessey, 2008). In other words, if IS research questions do not lead to knowledge contributions and help communicate them, they are not good research questions. On the whole, these roles highlight the crucial function of research questions in IS research.

While DSR is a distinct research paradigm in the IS discipline, three basic roles of research questions also apply to it: to define a project's scope (Hevner et al., 2004; Nunamaker, Chen, & Purdin, 1990), drive the

research process (Järvinen, 2008; Offermann, Levina, Schönherr, & Bub, 2009), and position the contributions (Gregor & Hevner, 2013; March & Smith, 1995).

However, the DSR literature also mentions two additional roles. First, only by posing innovative research questions can we achieve innovative artifacts, which are the key target of design science (Gregor & Hevner, 2013; March & Storey, 2008). Routine questions about artifacts referring to known solutions to known problems have no place in design science (Gregor & Hevner, 2013). Thereby, DSR research questions are concerned with helping to characterize design artifacts' innovative aspects. Second, DSR targets a knowledge void by posing relevant questions (Hevner & Chatterjee, 2010). By balancing relevance and rigor, good DSR research questions lead to knowledge contributions and practical contributions (Gregor & Hevner, 2013; Hevner, 2007). Further, formulating research questions seems to be common (although not uniformly adopted) practice in DSR publications. As we will show later in this paper, about two thirds of the examined DSR papers rely on research questions to frame their research, while the remaining ones rely on other alternatives, such as formulating research problems and design requirements.

Given the importance of research questions, we expect to find guidelines in the related literature supporting the construction and formulation of DSR-specific research questions. However, to the best of our knowledge, no such guidelines exist. The best approximations are guidelines for identifying high-level genres of inquiry (Baskerville, Kaul, & Storey, 2015) and a generic framework for identifying research objectives (Alismail, Zhang, & Chatterjee, 2017). This lack of guidance may be a contributing factor to many DSR papers not using research questions, which may mean that the paper might not realize its full knowledge contribution potential. This study aims to bridge this gap by analyzing recent DSR publications to synthesize guidelines on how to construct and formulate suitable DSR research questions.

3 Analytical Framework

In order to answer our research question, we first develop an analytical framework to help focus and bound our data collection by providing anticipatory data reduction (Miles et al., 2014). In our specific case, the analytical framework provides the structure required to analyze DSR publications with respect to how researchers constructed research questions in their studies. As characteristic of qualitative analysis, the framework also identifies the constructs required to later extract the fundamental elements related to DSR questions.

We developed our framework on the basis of two foundations: prior research on the construction of research questions – as a methodological concern that cuts across almost every discipline (Alvesson & Sandberg, 2013; Hassan, 2017; Higginbotham, 2000) – and the conceptualization and justification of design science as a distinctive research paradigm (Gregor & Hevner, 2013; Hevner et al., 2004; Nunamaker et al., 1990).

Figure 1 shows our proposed analytical framework. The framework highlights the three key activities of the research question life cycle: construction, formulation, and answer. Construction refers to how a researcher identifies opportunities for contributing to knowledge and builds key arguments to scaffold the research (Alvesson & Sandberg, 2013; Gregor & Hevner, 2013). This activity establishes the goals, motivations, and contexts for conducting the research. Formulation occurs when the researcher conveys the goals as specific research questions. A common skeleton for formulating research questions is a combination of form (what, how, why, who, and what?) and substance (what the research is about?) (Järvinen, 2008; Yin, 2013). Answer refers to the process where the research is conducted to finally answer the research questions. In DSR, the outcomes of this activity comprise generating innovative useful artifacts to provide knowledge and practical contributions (Hevner & Chatterjee, 2010; Hevner et al., 2004). Given the three activities, we identify the following seven core framework elements:

- Every study has a research **motivation**
- The research motivation contextualizes a **problem statement**
- The problem statement raises **research questions**
- The research questions drive the **research approach**
- The research approach is framed by **theory-in-use**
- The research approach suggests **research activities**
- Research activities generate IS **artifacts**

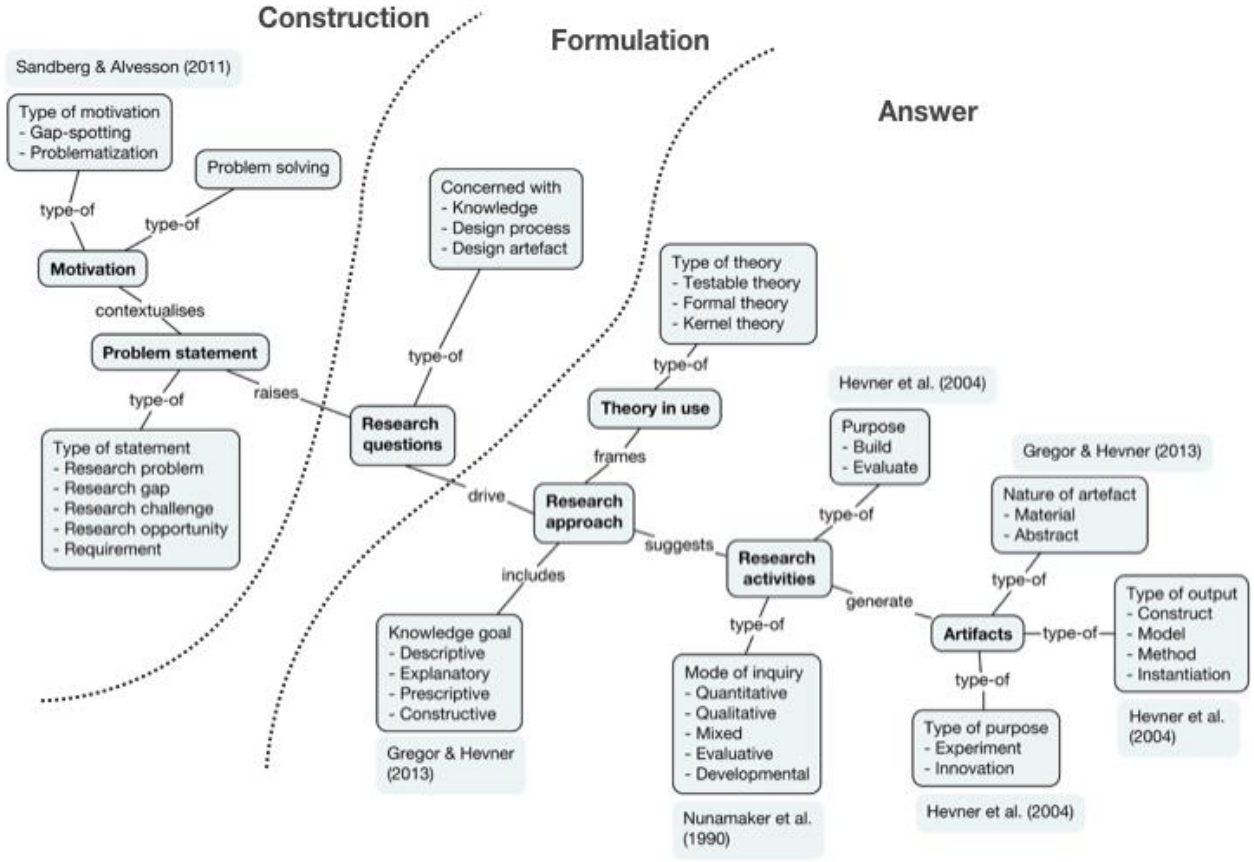

Figure 1. Analytical Framework

Considering the research motivation in more detail, Sandberg and Alvesson (2011) identify two major motivations for constructing research questions: gap-spotting and problematization. Gap-spotting refers to the identification of gaps in prior literature, leading to research questions that extend existing knowledge. Different types of gaps, including confusion in the existing literature, under-researched areas, overlooked areas lacking a specific focus, and areas lacking empirical support, motivate gap-spotting research. Problematization generates research questions by challenging well-established assumptions that underpin prior theory and knowledge. Logic-breaking arguments that go beyond a particular theory motivate problematization. research. Problematization research may challenge different levels and scopes of assumptions, including in-house, root metaphor, paradigm, ideology, and field assumptions (Alvesson & Sandberg, 2013). We add a new motivation for DSR to the existing two: problem-solving, which reflects the problem-solving nature of DSR (Pries-Heje & Baskerville, 2008). A practical and/or knowledge problem that can be solved by creating IS artifacts motivates problem-solving research.

The next element to consider is the problem statement, which articulates the problem that the DSR study addresses. Since DSR normally addresses wicked problems, the problem statement is useful for defining the research problem (Peffers et al., 2007), for clarifying its relevance (Hevner & Chatterjee, 2010), and for identifying the class of problems to which the addressed problem belongs (Gregor & Hevner, 2013). Experience shows that different DSR publications have different ways of presenting their problem statement: as a research problem, research gap, research challenge, research opportunity, and also as a list of requirements that a designed artifact needs to satisfy.

Thereafter, we consider the research questions that establish a DSR project's focus. Good research questions define what the DSR project is about and convey its essence (Hevner & Chatterjee, 2010; Sandberg & Alvesson, 2011). Since Section 2 has shown the roles of DSR research questions, we now focus on the formulation of DSR research questions. As noted previously, there are no current guidelines for formulating DSR research questions. On examining the DSR literature, we observe that many DSR studies focus on the design process, while others focus on the design product (Hevner et al., 2004). Consequently, we expect related types of questions. The former type focuses on "how" questions to move rationally from a particular problem to a solution (Gregor, 2006). The latter type focuses on "which" questions

that concern the types of artifacts that DSR generates. Finally, the last type we consider is "what is" questions, which concern design as both a process and a product. This type of questions refers to knowledge informing challenged by and originating from the research.

In relation to other elements, the research questions link the problem statements to the research approach. In the former relationship, research questions may arise from problem statements and refine and direct them to specific directions for inquiry (Offermann et al., 2009; Recker, 2012). As such, many DSR publications pose research questions as a single sentence in order to frame the problem statement. In the latter relationship, research questions drive the subsequent DSR approach as they set the directions for the selection of suitable research methods and research design to answer these questions (Järvinen, 2008).

At this stage, the research approach refers to how the researchers position their worldviews regarding their study (Creswell & Tashakkori, 2007). Järvinen (2008) and Creswell (2009) suggest that different research approaches link different research question formulations in the pursuit of different knowledge goals. Gregor and Hevner (2013) characterize research approaches' common knowledge goals as descriptive, explanatory, prescriptive, or constructive.

Related to the research approach, the theory-in-use concerns the theoretical statements supporting the research approach. Within this element, we find testable theory (which seeks to explain a phenomenon (Weber, 2012)), formal theory (which uses mathematics and logic (Bichler et al., 2016)), and kernel theory (which adopts theory from other fields (Gregor & Hevner, 2013)). Since the DSR literature may use other categories of theories, the framework is open to emerging categories during the subsequent literature analysis.

Regarding research activities, we understand that the main activities of DSR are building and evaluating, as suggested by Hevner et al. (2004). The building activity develops artifacts that enquire about the research question. The evaluating activity assesses the artifacts to show their utility. We also draw on the different modes of inquiry that Nunamaker et al. (1990) suggest: quantitative, qualitative, mixed, developmental, and evaluative.

The final elements we consider in the framework are the artifacts, which are the main DSR outcomes. In the related literature, we find different schemas to classify artifacts by addressing their nature, their type of purpose, and their type of output. Gregor and Hevner (2013) characterize artifacts' nature as either material or abstract. Hevner et al. (2004) characterize artifacts' purpose as either experiments or innovations. They also suggest four different types of outputs: constructs, models, methods, and instantiations. We do not provide a detailed discussion of these different elements, and refer the readers to the aforementioned references.

In sum, the analytic framework depicted in Figure 1 highlights the main elements of the research question's life cycle. Note that this framework is open to the identification of more detailed elements during our analysis of published research, which we explore in the following sections. Since DSR has evolved rapidly as a research paradigm, the framework is also open to new DSR advancements. With this openness in mind, we use the framework to guide our data analysis.

4 Methodology

In the current study, we follow the literature review method which has certain strengths and weaknesses when analyzing the DSR research questions' construction. On the one hand, by simply reviewing research questions in DSR publications, we cannot examine how they were constructed at the beginning of the relevant DSR projects or how they evolved over time. On the other hand, while "it is difficult to assess what research texts [publications] may say about how researchers really came up with their research questions at the beginning of their projects, the research text can be seen as the key stage in the formulation of research questions" (Sandberg & Alvesson, 2011, p. 25). Consequently, reviewing how a particular publication refers to its DSR research questions, allows us to understand the logic behind its claims. We can also examine how the final research questions are constructed and formulated by aligning the written research motivation, problem statement, research approach, research activities, and outcome artifacts. Further, in line with Sandberg and Alvesson (2011) and Hällgren (2012), the use of the literature review method is appropriate for analyzing and synthesizing research questions' construction. On the whole, this method enables us to extract and synthesize the existing ways of constructing research questions in the DSR literature.

In our literature review, we follow Webster and Watson's (2002) recommendations, which seek to increase transparency and reliability. We explicitly followed the following three review stages: definition of scope, data extraction, and data synthesis. Table 1 provides an overview of these stages, which are described in detail below.

Table 1. Three Literature Review Stages

Activity	Description	Results
Define scope	Select DSR publications for review	Dataset of 104 publications (21 MISQ papers, 20 PhD dissertations, and 63 papers published in the DESRIST and HICSS conferences)
Extract data	Extract the elements related to research questions	List of codes extracted from each reviewed publication, using the analytical framework as reference
Synthesize the extracted data	Compare, merge, and synthesize the extracted codes	Ways of constructing and formulating DSR questions

4.1 Define Scope

We searched for both mature and recently started DSR studies to form a representative pool of DSR publications. We surveyed papers published in MISQ between 2006 and 2017, as well as PhD dissertations, to find mature DSR studies. The search for PhD dissertations was initially done on ProQuest Dissertations and Theses Global, using the keywords "design science" and filtering "doctoral dissertations". We explored the search results to identify dissertations that explicitly stated they had adopted the design science paradigm. When more sources emerged, we decided to focus on 20 frequently cited dissertations. By including the doctoral dissertation genre, we opened our analysis to more extensive documentations of research activities. This openness includes the secondary artifacts used to support primary artifacts' development (Bertelsen, 2000), which may be deliberately missing from published papers to improve their conciseness. Further, we included papers from the DESRIST and HICSS conferences published in 2016 and 2017 to find emerging DSR studies. These two conferences are generally recognized as embracing the DSR paradigm.

In both cases, we specifically selected papers with a clear focus on design science per se, thus excluding literature reviews, editorials, and research notes. Our final dataset contained 104 publications, including 63 papers from DESRIST and HICSS (emerging publications), 21 papers from MISQ (mature publications), and 20 PhD dissertations (extensive publications). Appendix A presents a complete list of the publication dataset. This dataset should not be regarded as comprehensive, but as a representative sample of various DSR literature genres.

4.2 Data Extraction

We developed a coding form to extract data about research questions and their related elements. This coding form was derived directly from the analytical framework (Figure 1) and considered the following dimensions: 1) essential information required to identify the reviewed publication; 2) the research motivation and corresponding type; 3) the problem statement and corresponding type; 4) the various research questions (if any) limited to a maximum of four, the corresponding type, and specific terms characterizing the research questions; 5) the research approach, including the adopted theory (if any) and type of knowledge goals; 6) the research activities and type of inquiry adopted in the publication to address the research questions; and 7) the artifacts and their nature, their type of purpose, and their type of outputs. These elements provide us with the key logic of how the publications had constructed, formulated, and answered their DSR research questions.

We applied the coding form to all 104 publications for data extraction. Following Okoli's (2015) recommendations, the coding form was iteratively tested and adjusted by using a subset of the sources until an agreement was obtained. We then carefully read each publication and looked for the coding dimensions. Following Kitchenham et al. (2007), two of the authors conducted the coding process, while the third author randomly checked 20% of the coded items. When disagreements were identified, the team discussed these in detail to reach consensus. During the coding process, if a DSR publication explicitly offered statements on research question construction and formulation, these statements were noted and thereafter analyzed and synthesized.

4.3 Data Synthesis

This stage merged and synthesized the extracted data regarding the construction of DSR research questions. This synthesis was a four-step procedure. First, we reviewed the data that the coding form had extracted to identify the research questions' usage. Second, we merged and grouped related research questions into categories. For instance, we grouped the questions "how can competitive simulation games be used to…?" and "how the emerging hardware design and content design […] can be leveraged by retail stores to…?" into the "how can we [use]?" type of questions. Third, we synthesized the research-question-related elements, such as the research motivation, problem statement, and theoretical foundation, which provide the key logic for constructing a research question. This synthesis adopted Sandberg and Alvesson's (2011) typology for structuring research questions. Fourth, we mapped the research questions to the research approaches, activities, and outcome artifacts to determine their relationships. During this procedure, we also compared the data of the different DSR publications' genres. The next section reports the synthesis results.

5 Results

In this section, we report the research findings. Out of the 104 analyzed DSR publications, 64 publications have at least one research question. As expected, emerging publications (conference papers) have fewer research questions than mature and extensive publications (MISQ papers and dissertations). This finding suggests that the emerging publications either reflect ongoing or more focused research. Interestingly, 40 publications lack a specific research question. This lack, to some extent, confirms the challenge of formulating research questions in DSR.

Table 2 summarizes the detailed analysis results: how the research questions were constructed, their usage, and the ways adopted to address them. For reading Table 2, we note that that there may be a difference between the number of publications in a dimension and the total number of publications in its categories. The reason is that in some cases, a publication considers multiple values of a dimension and thus was coded multiple times (e.g. multiple research questions were founded and coded for (Lau, Liao, Wong, & Chiu, 2012)). In other cases, a publication does not clearly reflect the dimension and was coded 'not applicable'.

Research question construction. The results show that problem-solving is the main DSR motivation. 76.9% of the reviewed publications construct their research by basing it on stated problems. In this way of research question construction, a practical problem, design problem, or research challenge motivate DSR publications (Ketter, Peters, Collins, & Gupta, 2016; Mramba, Tulilahti, & Apiola, 2016). Another common way of research question construction is gap-spotting according to prior literature, which argues that there is a need to address an identified research gap. The least common way is based on problematization. We can identify only three such publications that challenge existing theories' assumptions (e.g. Pigott, 2012; Sahoo, Singh, & Mukhopadhyay, 2012; Tofangchi, Hanelt, & Kolbe, 2017).

We now consider how DSR publications state their problems. 36.5% identify research challenges, referring to problems with the research's complexity and often huge scope, in order to present their problem statements. An exemplar is the work by Ketter et al. (2016), who frame the grand challenge of sustainable electricity as their DSR problem statement. Other popular problem statements are the identification and description of research gaps (25.0%) and research problems (16.3%). Another interesting finding is that 12.5% of the publications use requirements to frame their problem statements. For instance, Llansó et al. (2017) guide their design process with a list of nine requirements. We believe that the usage of requirements is unique to design science in comparison to behavioral science. A possible reason for this usage may be DSR's strong ties to computer science, where requirements often lead research (Kampling, Klesel, & Niehaves, 2016; Newell & Simon, 1976).

Table 2. Summary of Results (n = 104)

#	Dimension	Value	Conference papers		MISQ papers		Dissertations		Total	
			n=63	%	n=21	%	n=20	%	n=104	%
Research question construction										
1	Motivation	Problem-solving	51	81.0%	18	85.7%	11	55.0%	80	76.9%
		Gap-spotting	21	33.3%	8	38.1%	13	65.0%	42	40.4%
		Problematization	1	1.6%	1	4.8%	1	5.0%	3	2.9%
2	Problem statement	Research challenge	18	28.6%	11	52.4%	9	45.0%	38	36.5%
		Research gap	15	23.8%	5	23.8%	6	30.0%	26	25.0%
		Research problem	12	19.0%	2	9.5%	3	15.0%	17	16.3%
		Requirement	11	17.5%	2	9.5%	0	0.0%	13	12.5%
		Research opportunity	5	7.9%	1	4.8%	1	5.0%	7	6.7%
Research question formulation										
3	Usage of RQ	Yes	36	57.1%	14	66.7%	14	70.0%	64	61.5%
		No	27	42.9%	7	33.3%	6	30.0%	40	38.5%
4	Types of RQ	Design process (How?)	35	55.6%	27	128.6%	18	90.0%	80	76.9%
		Design product (Which?)	3	4.8%	2	9.5%	15	75.0%	20	19.2%
		Knowledge (What is?)	0	0.0%	0	0.0%	3	15.0%	3	2.9%
		Other	3	4.8%	2	9.5%	1	5.0%	6	5.8%
5	Research approach - knowledge goal	Exploratory	24	38.1%	4	19.0%	5	25.0%	33	31.7%
		Prescriptive	17	27.0%	8	38.1%	7	35.0%	32	30.8%
		Constructive	7	11.1%	4	19.0%	1	5.0%	12	11.5%
		Confirmatory	7	11.1%	2	9.5%	1	5.0%	10	9.6%
		Explanatory	6	9.5%	0	0.0%	1	5.0%	7	6.7%
		Descriptive	2	3.2%	2	9.5%	3	15.0%	7	6.7%
6	Research activities - mode of inquiry	Developmental	30	47.6%	9	42.9%	14	70.0%	53	51.0%
		Evaluative	3	4.8%	1	4.8%	0	0.0%	4	3.8%
		Mixed (developmental and evaluative)	26	41.3%	9	42.9%	4	20.0%	39	37.5%
7	Theory-in-use	No specific theory	34	54.0%	3	14.3%	10	50.0%	47	45.2%
		Kernel theory	13	20.6%	14	66.7%	5	25.0%	32	30.8%
		Formal theory	4	6.3%	3	14.3%	4	20.0%	11	10.6%
		Testable theory	0	0.0%	1	4.8%	1	5.0%	2	1.9%
8	Outcome artifacts	Instantiation	19	30.2%	6	28.6%	3	15.0%	28	26.9%
		Model	15	23.8%	4	19.0%	4	20.0%	23	22.1%
		Method	6	9.5%	2	9.5%	3	15.0%	11	10.6%
		Construct	3	4.8%	2	9.5%	4	20.0%	9	8.7%
		Model and Instantiation	11	17.5%	3	14.3%	2	10.0%	16	15.4%
		Construct, Model, and Instantiation	3	4.8%	0	0.0%	3	15.0%	6	5.8%

Research question formulation. 61.5% of the publications define at least one research question. However, many define more than one research question. Figure 2 summarizes the distribution of publications with one, two, three, and four research questions. Conference papers tend to have a single research question, while MISQ papers and dissertations have more than one. These results support the view that a conference outlet is a different genre of research publication, tending to be more focused and streamlined.

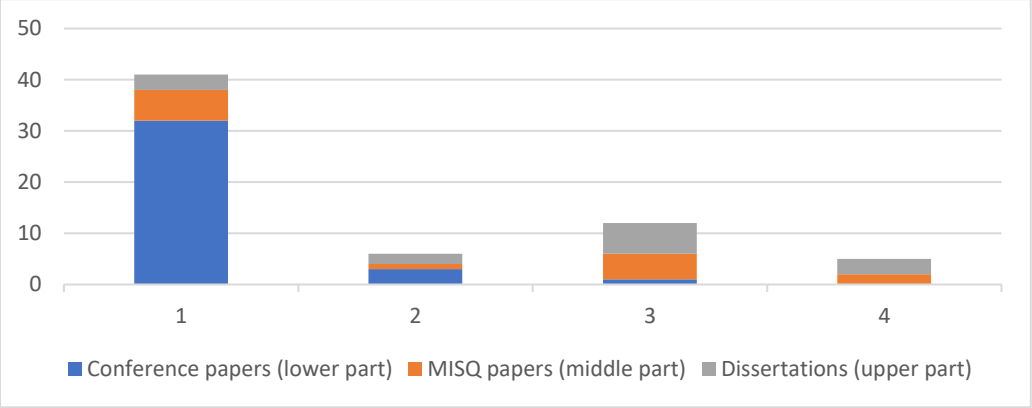

Figure 2. Number of publications that formulate one, two, three, and four research questions

Characterizing the research questions, the results show that "how can we?" that addresses the design process is the most popular type, formulated in 76.9% publications. This type of question emphasizes the methods' and procedures' development (Haj-Bolouri, Bernhardsson, & Rossi, 2016) and design artifacts' implementation and operationalization (Mramba et al., 2016). This formulation is particularly high in MISQ papers, with several publications formulating more than one such question, leading to 27 process-related questions in 21 publications. For instance, Chou et al. (2014) define three process-related questions that guide their research (e.g. how can we process, how can we implement, and how can we evaluate?).

The next popular type is the artifact-related question (19.2%). This type of question emphasizes the DSR research product, including the "which components?" and "which properties?" questions defining the product (Thomas & Bostrom, 2010; Zoet, 2014). Regarding the knowledge-related question, we find a surprisingly small number of the "what is?" question addressing prior and new knowledge related to the research: 2.9% of the questions address prior knowledge and are only used in dissertations; there are no questions addressing new knowledge. A possible explanation for these sparse results could be that researchers treat knowledge as being beyond research question formulation's scope, preferring to address it in related work and in the discussion/contribution sections. Finally, in addition to these types of questions, we coded six publications in the 'other' category, which emphasizes the notion that DSR studies can embed a diversity of inquiry modes and research methods (Baskerville et al., 2015), which research questions' diverse formulations reflect.

Since research question construction and formulation are the focus of the current paper, we cover and discuss the detailed results in Sections 6 and 7.

Research question answer. Considering the research approach, we highlight exploratory research's dominance (31.7%). We also observe a notable difference in the number of exploratory research papers between conference papers (38.1%) and both MISQ papers (19%) and dissertations (25%). This supports the view that the conference genre embraces emerging exploratory results, while journal papers and dissertations cover more mature research results. The next most popular approaches are those with prescriptive and constructive knowledge goals, which reflect the DSR methods and design principles guiding the construction of artifacts.

Addressing the DSR activities, our results confirm that building and evaluating are the two main DSR activities. The two main modes of enquiry are developmental (51%) and mixed (comprising both developmental and evaluative) (37.5%). We identified only four publications adopting the evaluative mode. This small number suggests that, in design science, it may be difficult to only report on evaluation activities. The artifact evaluation may have to be mixed with the building activity.

We identified a high number of publications that do not use any theory at all (45.2%). A recent literature survey (Thakurta, Müller, Ahlemann, & Hoffmann, 2017), which found that 46% of the DSR studies in their sample are based on argumentative deduction not theories, also found that 26% of the studies are based on neither argumentative deductions nor theories, thus supports our findings. Omitting publications that do not use any theory, we find that 30.8% of the publications use kernel theories and 10.6% formal theories to approach their research.

We finally consider the outcome artifacts. Instantiations and models are the predominant DSR outcomes in respectively 26.9% and 22.1% of the publications. Interestingly, 21.2% of the publications have more than

two artifact outcomes. We subsequently mapped these DSR outcomes to the research question formulation. The results indicate that instantiations and methods are usually derived from process-related questions. We also observed that process-related questions could lead to paired artifacts, such as method and instantiation (Lee, Wyner, & Pentland, 2008), and model and instantiation (Lau et al., 2012). In addition, we found cases generating three artifacts: method, model, and instantiation (Haj-Bolouri et al., 2016).

6 Constructing Research Questions in Design Science

In this section, we further our understanding of how DSR constructs research questions. As presented in the previous section, the three basic types of DSR research question construction are: problem-solving, gap-spotting, and problematization. We adopted Gregor and Hevner's (2013) framework and Sandberg and Alvesson's (2011) typology to further analyze the specific modes within these types of research question constructions.

We used the DSR knowledge contribution framework proposed by Gregor and Hevner (2013) to analyze how DSR constructs problem-solving research questions, because "constructing research questions and creating an opportunity for contribution are fairly close in the sense that a created space for contribution points to a specific question, and vice versa" (Sandberg & Alvesson, 2011, p. 26). Two dimensions form this framework: problem maturity and solution maturity. The combination of these dimensions defines four quadrants: routine design (known problem and known solution), improvement (known problem and new solution), exaptation (new problem and known solution), and invention (new problem and new solution). The first quadrant, in which both the problems and the solutions are well-defined, rarely requires design science, and was omitted from our analysis. The three other quadrants, characterized by the unknown problems and/or the unknown solutions, are areas for DSR and used in our analysis.

We then used Sandberg and Alvesson's (2011) typology to analyze how DSR constructs gap-spotting and problematization research questions. These scholars' typology allows us to clearly categorize different ways of constructing gap-spotting and problematized research questions, which are summarized in Section 3. Gap-spotting includes under-researched areas, overlooked areas lacking a specific focus, confusion, and areas lacking empirical support. Problematization includes in-house, root metaphor, paradigm, ideology, and field assumptions.

Table 3 presents the three basic types of DSR research question construction and their specific modes, which are elaborated below.

Table 3. Detailed Results for DSR Research Question Construction (n=104)

Dimension	Value	Conference papers		MISQ papers		Dissertations		Total	
		n=63	%	n=21	%	n=20	%	n=104	%
Problem-solving	Improvement	44	69.8%	13	61.9%	9	45.0%	66	63.5%
	Exaptation	7	11.1%	5	23.8%	2	10.0%	14	13.5%
	Invention	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Gap-spotting	Under-researched	11	17.5%	1	4.8%	7	35.0%	19	18.3%
	Overlooked	3	4.8%	2	9.5%	4	20.0%	9	8.7%
	Lacking empirical support	7	11.1%	5	23.8%	2	10.0%	14	13.5%
Problematization	In-house assumptions	1	1.6%	1	4.8%	1	5.0%	3	2.9%
	Other problematization	0	0.0%	0	0.0%	0	0.0%	0	0.0%

Problem-solving. The most dominant way of constructing DSR research questions in our dataset is the problem-solving mode. Its main focus is to identify certain kinds of problems (e.g. practical problem, design problem, research problem, and research challenge) and to build solution artifacts that address these. DSR research adopting this construction usually mentions that 'this research addresses the problem/challenge …' (Ketter et al., 2016; Mramba et al., 2016). In the reviewed publications, we identify two problem-solving modes: improvement and exaptation.

The improvement mode aims at building new solution artifacts for known problems. Half of the reviewed publications use the improvement mode, positioning it as the most popular form of constructing DSR research questions. An example of this mode is the study by Abbasi et al. (2010) addressing the problem of detecting fake websites, which is a known application problem. This problem led the authors to construct

research questions based on the argument that the existing detecting systems had shortcomings and an improved solution with "a new class of fake website detection systems" (p. 436) was needed. They subsequently built the solution artifact and conducted a series of experiments showing that these new solutions were an improvement on the existing systems. The works by Adams (2013) and Mramba et al. (2016) are more examples of constructing DSR improvement research questions by proposing new solution artifacts for known problems.

In the improvement mode, the new solution artifacts vary. They can be instantiation artifacts, such as the fake website detection system in the above example. They can also be solutions in the form of proposed constructs, methods, and models as improvements on those of an existing problem (Haj-Bolouri et al., 2016; Osterwalder, 2004). An example of the latter is Osterwalder's (2004) study of how business models can be better described. He built his study on the argument that existing business models were abstract and vague, thus needing improvement. This led him to construct the research question: "How can business models be described and represented in order to build the foundation for subsequent concepts and tools, possibly computer based?" (p. 2). Addressing this question, the study built a set of artifacts, including the constructs, models, and instantiations.

The exaptation mode refers to the construction of research questions that link artifacts in a field to a new problem context. One tenth of the reviewed publications use the exaptation mode. Larsen and Bong (2016) provide an example of this mode by focusing on the problem of detecting a construct identity, which is an emerging problem in large-scale literature reviews and meta-analyses. The authors addressed this problem by adapting and combining different natural language processing algorithms. They therefore framed "this article as exaptation research: applying known solutions to new problems" (p. 530). Other examples of adapting solutions from a field to a new problem contexts are the works by Braun et al. (2016) and Lin et al. (2017).

Finally, none of the reviewed publications uses the invention mode. This mode addresses radical breakthroughs where "little current understanding of the problem context exists and where no effective artifacts are available as solutions" (Gregor & Hevner, 2013, p. 345). The rare usage of the invention mode is hardly surprising, since true inventions are, in fact, rare. Further, inventions need time to be established and recognized; researchers may therefore position them in their initial publications as either improvements or exaptations. Another explanation concerns the granularity with which the problem is viewed. Given a small enough problem space, almost all the solutions could be considered inventions. On the other hand, given a large enough problem space, which could apply to the current case, very few inventions would be conspicuous.

Gap-spotting. The second dominant way of constructing DSR research questions is the gap-spotting mode. In contrast to the problem-solving mode, where the research questions may come from practice, gap-spotting focuses on identifying a gap in the literature and suggesting an artifact to bridge it. Publications adopting this way of research question construction normally claim that 'there is a gap in …' (O'Leary, Mtenzi, & McAvinia, 2016) and 'little research/guidelines exist …' (Parsons & Wand, 2008). In the reviewed publications, we identified three modes of gap-spotting: under-researched, overlooked, and lacking empirical support.

Under-researched publications follow the line of reasoning that there is a void in the literature that needs to be researched. Nearly one fifth of the reviewed publications use the under-researched mode. Parsons and Wand (2008) provide an example of this mode. Focusing on IS artifacts' classification, they built their research question on the argument that there was no well-grounded guidance for choosing IS modelling classes. The authors supported their argument by reviewing the literature and identifying the under-researched gap that "this literature primarily offers guidance or techniques for identifying candidate or potential classes for a domain, but does not offer grounded criteria for evaluating these possible classes […] and choosing among them" (p. 842). This led them to build a model and a method of classification to bridge the gap.

Similar to the under-researched mode, the overlooked mode also identifies a gap in the literature. The difference is that the overlooked mode searches for gaps in well-established areas that lack a specific focus. An example of the overlooked argument is that the existing research in a specific area is fragmented, leaving room for an integrated view. Nardi's (2014) study followed this approach by arguing that the notion of service was conceptualized differently in different application sections, requiring "a unified view of the notion of service" (p. 18). He subsequently constructed a common reference ontology of the service concept in order to bridge the overlooked gap.

The last gap-spotting mode in the reviewed publications concerns the lack of empirical support. This mode argues that the existing research is inconclusive and that more empirical research is needed. Examples are the work by Raber (2016), and Tagle and Felch (2016). Interestingly, several publications using the lack of empirical support mode also use the problem-solving improvement mode. These DSR publications identify an empirical gap in the literature, and bridge this gap by constructing solution artifacts and evaluating them (Adipat, Zhang, & Zhou, 2011; Thomas & Bostrom, 2010). The empirical results show the usefulness of the solution artifacts (e.g. an improvement mode) and address the lack of empirical support (e.g. a lacking empirical support mode).

Problematization. The problematization mode refers to deficiencies in existing theories, thus requiring further research to remedy them. This mode is not particularly common in the reviewed publications, with only three instances of problematization, namely the in-house assumption challenging "a particular school of thought" (Alvesson & Sandberg, 2013, p. 52). These results are consistent with the on-going calls for further theorizing in design science (Germonprez, Hovorka, & Collopy, 2007; Gregor & Jones, 2007). An example of DSR problematization is Sahoo et al.'s (2012) study on recommender systems, which claims that recommender systems are usually "based on the assumption that a user's preference is a static pattern" (p. 1331). The authors challenge this assumption, arguing that "users' product selection behaviors change over time" (p. 1329), leading them to propose a model for capturing a dynamic user's preference.

Overall, we have presented the basic ways in which DSR researchers construct research questions. The two major ways are problem-solving and gap-spotting, with only a few publications problematizing the underlying assumptions or theories. This section has extended the Alvesson and Sandberg (2011) typology in respect of two aspects. First, we add problem-solving to the typology as an additional way of DSR research question construction. In the reviewed publications, problem-solving is the most dominant way of constructing DSR research questions. Second, we confirm that the usage of gap-spotting and problematization in DSR research and the logic for constructing gap-spotting and problematization research questions in DSR are similar to those of management research (e.g. Sandberg & Alvesson, 2011). Nevertheless, the corresponding research activities differ. The main research DSR activities are building and evaluating, whereas management research's main research activities are theory building and theory testing.

7 Formulating Research Questions in Design Science

This section explores how DSR research questions are formulated. As presented in Section 5, 64 of the 104 reviewed publications formulate at least one research question in the three basic types: how? (design process), which? (design product), and what is? (knowledge). Table 4 provides a more detailed research question classification.

Table 4. Detailed Results for DSR Research Question Formulation (n=64)

Dimension	Value	Conference papers		MISQ papers		Dissertations		Total	
		n=36	%	n=14	%	n=14	%	n=64	%
How can we [ ]?	Process	13	36.1%	8	57.1%	6	42.9%	27	42.2%
	Use	6	16.7%	4	28.6%	9	64.3%	19	29.7%
	Evaluate	2	5.6%	10	71.4%	2	14.3%	14	21.9%
	Represent	6	16.7%	3	21.4%	1	7.1%	10	15.6%
	Implement	8	22.2%	2	14.3%	0	0.0%	10	15.6%
Which [ ] define?	Components	3	8.3%	2	14.3%	4	28.6%	9	14.1%
	Properties	0	0.0%	0	0.0%	7	50.0%	7	10.9%
	Requirements	0	0.0%	0	0.0%	4	28.6%	4	6.3%
What [ ] is available?	Prior knowledge	0	0.0%	0	0.0%	3	21.4%	3	4.7%
	New knowledge	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Other		3	8.3%	2	14.3%	1	7.1%	6	9.4%

The most dominant way of formulating DSR research questions is "how can we?", which emphasizes DSR's design process outcome. We can also distinguish five specific genres of "how can we [ ]?", namely [process], [use], [evaluate], [represent], and [implement]. In the reviewed publications, the most popular research

question is “how can we [process]?”, which is used in 42.2% publications. Studies in this category emphasize the development of methods and procedures, and the design principles for these procedures. “How can we [use]?” questions are also common and used in 29.7% publications. This category investigates the operationalization and use of design artifacts to address the identified problems. Other common genres are “how can we [represent]?”, “how can we [implement]?”, and “how can we [evaluate]?” Studies in these categories emphasize the model development in a domain of interest, the instantiation’s implementation, and specific artifacts’ utility.

“Which?” questions emphasizing the DSR research product outcome are also common. We find various genres of the “which [ ] define?” question, including [components], [properties], and [requirements] reported in respectively nine, seven, and four publications. While all the studies examine the outcome artifacts, these questions focus on different design stages ranging from defining the requirements, specifying the properties, to developing artifact components.

“What is?” questions emphasize the knowledge contributions. They are not particularly common in the reviewed publications. We can further distinguish two specific genres of “what [ ] is available?”, namely [prior knowledge] and [new knowledge]. While three reviewed publications adhere to the category “what prior knowledge is available?”, none of the reviewed publications adheres to the category “what new knowledge is available?” Even though these results could suggest that these genres should be disregarded as irrelevant, we nevertheless believe that DSR should consider them. We argue that these questions are implicit in DSR, which is expected to demonstrate adequate use of the existing knowledge base and also demonstrate distinct knowledge contributions (Gregor & Hevner, 2013). We therefore suggest making these question genres more explicit and integrating them fully into a DSR publication.

Overall, the results identify the ten basic genres in which researchers have expressed DSR research questions. These genres show the basic research question forms that need to be combined with actual substance in the form of project and context-specific constructs or artifacts, thus allowing actual and complete DSR research questions. Future DSR projects can draw on these basic forms to develop research questions across the range of DSR genres (e.g. what prior knowledge is available, how can we process, how can we use, how can we evaluate, how can we represent, how can we implement, which components define, which properties define, which requirements define, and what new knowledge is available?) and combine them with project and context-specific artifacts.

7.1 Typology of DSR Research Questions

To further support the DSR research question formulation, we provide a typology describing how DSR researchers have expressed research questions. The typology’s aim is not to constrain DSR researchers to a set of rules on the ‘right’ research questions. Instead, the topology provides a foundation for formulating and expressing future research questions. While different ways of building typologies can be adopted, we followed Bailey (1994) and adopted the conceptual-to-empirical approach. This approach starts with a conceptual typology structure and subsequently uses it to examine the empirical cases for building profiles of each typological element.

In the conceptual activity, we developed a structure that frames the question genres identified in Table 4. The outcome is the hierarchical typology shown in Figure 3, which distinguishes different ways of doing DSR research, related research question articulations, and their specific concerns.

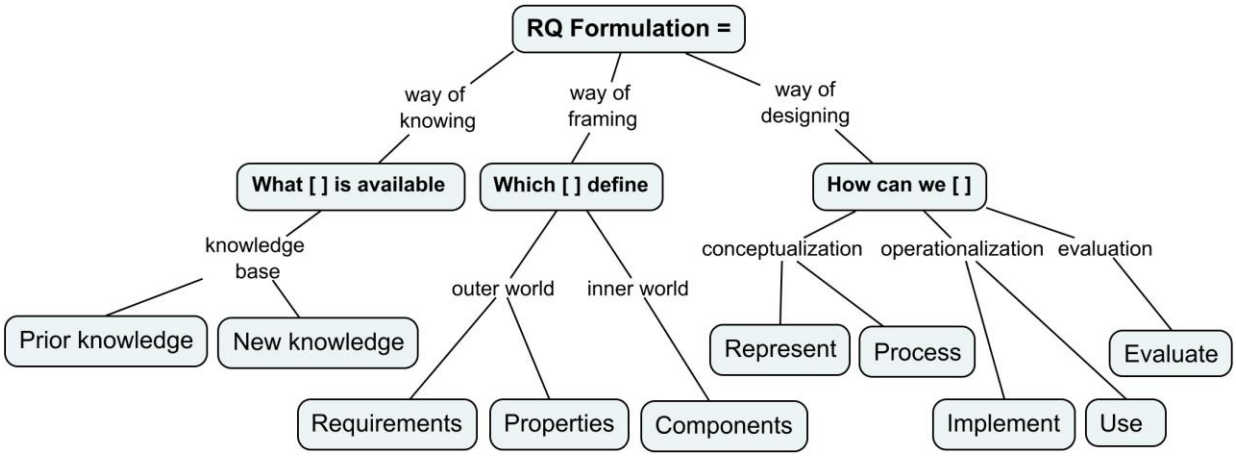

Figure 3. Typology of DSR Research Questions

The top of this typology classifies three different ways of doing research: way of knowing, way of framing, and way of designing. These categories respectively address the acquisition and generation of knowledge about artifacts (Gregor & Hevner, 2013), the frame of what has to be designed (i.e. the object of attention (Schön, 1984)), and the consideration of how to design the artifacts (Hevner et al., 2004; Peffers et al., 2007). Each category leads towards a specific research question articulation.

The way of knowing leads to the "what [ ] is available?" question genre, which directs inquiries about the knowledge base. This genre seeks to answer what was known before the research and what new knowledge will be known after the research. While we found only a few publications explicitly formulating questions in this genre, we also found that many publications implicitly address both the prior knowledge and the contributed knowledge in the foundational and the discussion sections. Given the importance of the research questions in this genre and the wide range of potential knowledge contributions to DSR, our typology suggests moving from implicitness to explicitness. In other words, these research questions can be a very helpful tool for scaffolding the links between the research and the knowledge base, thus making them even more explicit.

The way of framing leads to the "which [ ] define?" question genre, which aims to characterize an artifact as the object of attention. For a further distinction within this genre, we adopt Simon's (1996) distinction between inner and outer worlds. The inner world concerns an artifact's internal structure, i.e. the components put together to materialize the artifact. The outer world concerns the requirements and properties constraining the artifact's existence or usefulness. Requirements normally prescribe properties to which an artifact has to conform. Requirements are closely related to the artifact's uses, while properties are more related to its identity.

Finally, the way of designing leads to the "how can we [ ]?" question genre, which concerns the activities required to realize an artifact. According to Table 4, this genre is the most common of the three. We divide this genre into three further concerns. First, we have to conceptualize the artifact, which concerns both the artifact representation ("how can we [represent]?") and the activities necessary to achieve it ("how can we [process]?"), with both reflecting design's complementary perspectives as a noun and a verb (Gregor & Jones, 2007). Second, we have to operationalize the artifact. Two complementary aspects of operationalization are implementation ("how can we [implement]?") and use ("how can we [use]?"). Finally, since design always involves some type of evaluation, we also have to consider this aspect in the design approach. This leads to the genre of "how can we [evaluate]?"

Overall, this typology narrows down the research question formulation from the abstract ways of doing DSR to specific questions that logically express specific areas of concern. Furthermore, given the predominant developmental mode of inquiry, this typology also suggests ways of structuring DSR research by using multiple research questions that address the way of knowing, way of framing, and way of designing.

To complete the typology, we next built the empirical profile of each genre of DSR research questions. To this end, we grouped the research questions identified in the literature according to the typology of DSR questions. We conducted a pattern matching analysis of each genre (Yin, 2013). We looked for similarities and differences between the questions, which enabled us to identify common patterns and terms used for

each genre. Table 5 summarizes the results and also includes the "what [new knowledge] is available?" question, for which we have not found evidence in our sample. The suggested patterns of this particular question are extrapolated from the use of the "what [prior knowledge] is available?" question.

Table 5. Profile of DSR Research Questions

Genres of RQ	Suggested patterns
What [prior knowledge] is available?	What current understanding of X is addressed? What current knowledge about X is available? How can an understanding of X be achieved?
What [new knowledge] is available?	What new understanding of X can be achieved? What new knowledge does X contribute?
Which [components] define?	What are the essential components of X? Which components define X? What components should X include?
Which [properties] define?	Which properties characterize X? Which are the important properties of X? What are the commonalities of X? What would characterize X?
Which [requirements] define?	Which requirements define X?
How can we [represent]?	How can we model X? How can we represent the elements of X? How can X's elements be combined in model Y? What typifies X's ontology?
How can we [process]?	How can we conduct X? How can we elaborate X? What is a suitable way of doing X? Which strategy can be used for X?
How can we [use]?	How can we use X? How can we operationalize X? How can we apply X? How should X be utilized?
How can we [implement]?	How can we implement X? How can we develop X? Can X be implemented?
How can we [evaluate]?	How can we evaluate X? What evaluation measures can be used to assess X? In what way can X be improved?

Table 5 proposes genres of DSR research questions and shows patterns associated with each genre. We highlight the complementarity of Table 5 and the typology shown in Figure 3. Table 5 shows how empirical patterns identified in the reviewed sample of publications fit the conceptualization[1]. We therefore suggest using Table 5 together with the typology. DSR researchers can relate their research to the typology to identify appropriate research questions and to draw on the suggested patterns to actually formulate their questions. By considering the way of knowing, way of framing, and way of designing, researchers could use a set of questions to start and scope a DSR project. However, the DSR project will probably evolve over time. It is therefore also important to understand how researchers can use the typology to provide a set of consistent questions that support DSR projects' evolution. This is the focus of the next section.

7.2 Using the Typology in Hevner's DSR Cycles

This section illustrates how the typology can align with DSR projects' progress. According to Hevner (2007), DSR projects progress through three cycles: relevance, design, and rigor. The relevance cycle links the application domain with the DSR effort, suggesting the requirements and, specifically, requiring the artifact to be applied to the application domain in order to validate its practical usage. The design cycle iterates between two DSR activities: building and evaluating. Finally, the rigor cycle grounds the other cycles on the

[1] With the exception of "what [new knowledge] is available?" mentioned in the previous paragraph.

existing knowledge base and, due to the research activities, mandates that new knowledge should be added to the knowledge base.

To demonstrate how the typology can fit the DSR projects' progress, Figure 4 maps the DSR research question genres to the three cycles. We also add a sequence that follows the logical progress through the cycles to these research questions.

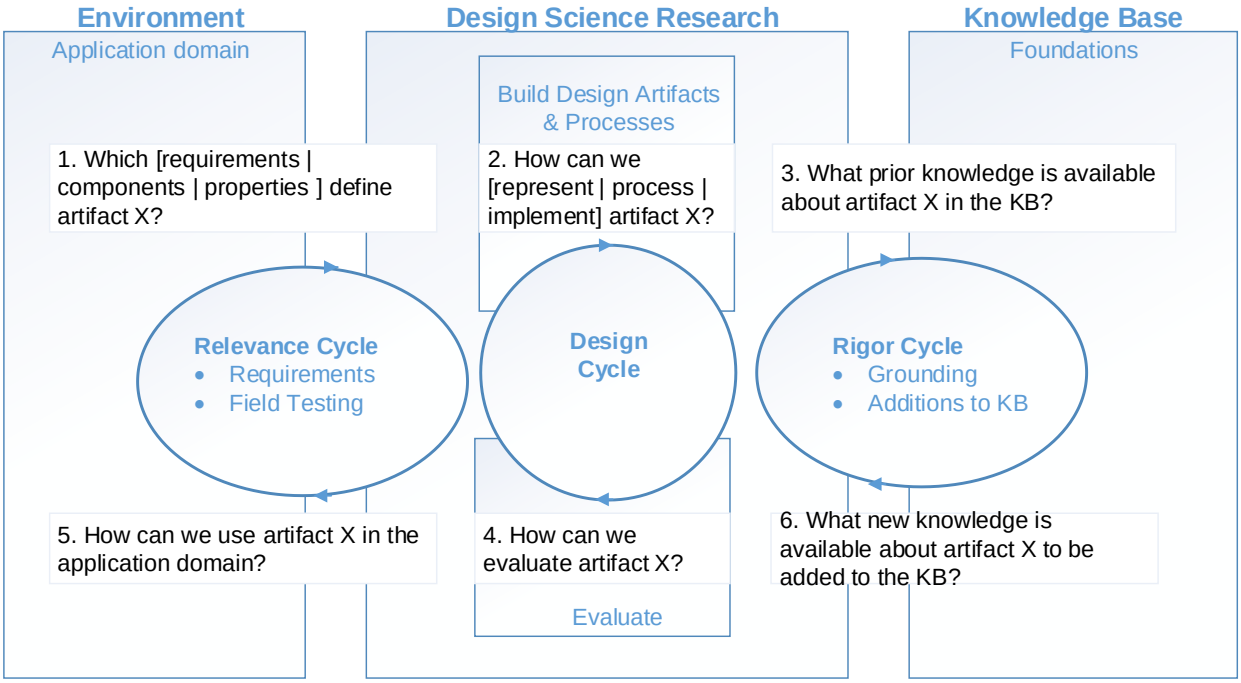

Figure 4. Positioning the DSR genres in Hevner's three-cycle view (adapted from Hevner, 2007)

At the beginning, the DSR project explores the target artifact's requirements obtained from the application domain (Hevner, 2007), thus asking "which requirements define the artifact?" The requirements' exploration should begin with the outer world, i.e. the requirements, and then consider the inner world, i.e. the artifact's properties and components. Given the list of requirements, the DSR project then moves to the building activity. Different questions can be formulated in this activity, including "how can we represent the artifact?", "how can we process the artifact?", and "how can we implement the artifact?" In respect of the building activity, the DSR project also needs to define the artifact's knowledge foundation by asking "what prior knowledge is available about artifact X, which can be grounded on the knowledge base (KB)?"

After the building activity, the DSR project moves to the evaluating activity, formulating "how can we evaluate the built artifact?" Thereafter, the DSR project returns the artifact to the application domain. This poses the next question, namely "how can we use the artifact in the application domain?" Addressing all of the above questions may generate new knowledge, not only about the artifact's innovativeness, but also about the methods adopted to develop the artifact, or about the application domain. Since knowledge contributions are key for communicating a DSR project's outcomes to an academic audience (Hevner & Chatterjee, 2010), we suggest that DSR should explicitly address the question "what new knowledge is available about the artifact and the context that can be added to the knowledge base?"

Overall, we suggest that the different genres in the typology enable DSR researchers to articulate specific research questions over the course of a DSR project. As the project evolves, the typology can help formulate the next set of research questions for each cycle. Furthermore, we also suggest that DSR research questions are not static constructs during DSR projects, but evolve dynamically throughout them. Reflecting this dynamic, we suggest that the typology should be used as an open frame that informs the basic DSR genres and accepts new DSR genres.

We now derive practical guidance for DSR researchers on how to formulate research questions in DSR projects. In Table 6, we provide basic templates that can be used to formulate research questions for the development of common artifacts: construct, model, method, and instantiation. We suggest a set of research questions for each artifact type, starting with the relevance cycle and moving to the design cycle and the rigor cycle. A DSR project may draw on only a part of the template, on different parts of the template, may

add other research questions, and may combine these templates when the project aims to develop multiple artifacts. We emphasize DSR research's diversity and openness if different research questions can be posed in respect of a specific artifact. Table 6 shows how the profiles fit such diversity.

Table 6. Templates for DSR Research: Research question formulation and corresponding expressions

Goal	Suggested template
Develop model	**Which** requirements define the [model]? **What** prior knowledge is available about the [model]? **What are** the [model]'s essential components? **How can we** represent the [model]? **How can we** evaluate the [model]? **What** new knowledge does the [model] contribute?
Develop method	**What are** the essential requirements for designing the [method]? **Which** essential properties characterize the [method]? **What** prior knowledge is available about the [method]? **How can we** elaborate (process) the [method] to be compliant with the set of [requirements, properties]? **How can we** implement the [method]? **How can we** evaluate the [method]? **How can we** use the [method]? **What** new knowledge does the [method] contribute?
Develop construct	**Which** essential properties characterize the [construct]? **What** prior knowledge is available about the [construct]? **How can we** represent the [construct]? **How can we** operationalize the [construct]? **How can we** use the [construct]? **What** new knowledge does the [construct] contribute?
Develop instantiation	**What are** the essential requirements for designing the [instantiation]? **Which** essential properties characterize the [instantiation]? **Which** essential components constitute the [instantiation]? **How can we** represent the [data, functional, behavioral…] structure of the [instantiation]? **How can we** elaborate a process to design an [instantiation] compliant with the set of defined [requirements, properties, components]? **How can we** implement an [instantiation] that operationalizes the set of [requirements, properties, components]? **What** prior knowledge is available about the [instantiation]? **How can we** evaluate the [instantiation]? **How can we** use the [instantiation]? **What** new knowledge does the [instantiation] contribute?

Note: To increase readability of Table 6, the research question forms are presented in **bold font,** the areas of concerns are presented in underlined font, and the substances or artifacts are presented in [].

8 Discussion

Given the DSR paradigm's distinct nature, we conceptually and empirically investigated DSR research questions' construction and formulation. Nunamaker et al. (1990) and Hevner and Chatterjee (2010) state that future DSR publications should state their research questions clearly. Clear research questions help DSR projects define their focus, drive the research approach, and position the research contributions. In our analysis of the research questions of 104 DSR publications, we find that about two thirds of the examined DSR publications (61.5%) explicitly use research questions in order to link the problem statements to the chosen research approaches. Consequently, we highlight and reinforce the role of research questions in DSR, allowing future DSR research questions to match the importance of research questions in the IS discipline (Dubé & Paré, 2003; Recker, 2012; Venkatesh et al., 2013). We further provide DSR researchers with additional guidance, thus helping researchers to fully exploit their DSR projects' knowledge contribution potential in their publications.

A distinct aspect that distinguishes DSR from other research paradigms is that problem-solving is its dominant way of research question construction (see Section 6). This finding is not only a further validation of DSR's problem-solving nature (Hevner et al., 2004; Nielsen & Persson, 2016), but also underlines the need for a unique way of formulating research questions suitable for problem-solving. We also point out the

under-utilization of problematization in existing DSR publications, in which research questions are constructed by challenging the existing theoretical status quo beyond 'superficial' gap-spotting or the identification of real-world problems. We would therefore encourage design-oriented researchers to incorporate problematization into their repertoire, which will provide deeper and richer knowledge contributions beyond the development of innovative and useful artifacts.

Another distinctive DSR aspect is that its research questions can reflect the predominantly developmental approach to research. We find that a number of studies adopted multiple, logically related research questions ranging from the way of knowing, to the way of framing, and to the way of designing (Figure 3). To further highlight DSR's contribution to the knowledge base beyond artifacts, we suggest including a particular question – "what [new knowledge] is available?" – for which we could not find evidence in the literature review. We envisage DSR studies structured in such a way that they combine the "what [prior knowledge] is available?" question with the "which [ ] define?", "how can we [ ]?", and "what [new knowledge] is available?" questions. This way, researchers can scaffold the whole knowledge-generating research process – not just the design-oriented part – through using research questions.

We also find differences in the research question construction in the publication genres. Problem-solving dominates the paper outlet with 83.3% of the journal and conference papers, but not the dissertation outlet, with only 55% of the dissertations. In a similar vein, the way of designing dominates the paper outlet, but not the dissertation outlet. In the paper outlet, the way of designing leads to 62 questions (versus 5 questions pursuing the way of knowing and way of framing). In the dissertation outlet, the proportion is more balanced (18 questions pursuing the way of designing versus 18 questions pursuing the way of knowing and the way of framing). On the whole, the combination of problem-solving and the way of designing suggests that DSR papers tend to emphasize pragmatism. More research may be required to understand why DSR papers seem to devalue the way of knowing and the way of framing in their research question construction.

When examining the approaches to answering DSR research questions, we identified three interesting points. First, the predominant mode of inquiry for answering DSR research questions is the developmental mode (53% developmental and 39% a combination of developmental and evaluative). This is consistent with the high number of "how can we [ ]?" and "which [ ] define?" questions found in the publications. Second, we identified a high number of publications without theory-in-use, which is also consistent with the emphasis on problem-solving rather than on gap-spotting or problematization. Third and last, we find that model and instantiation are the most frequently developed artifacts, which is in line with another recent study's findings (Thakurta et al., 2017). These three approaches can be seen as mutually reinforcing and internally consistent.

To help formulate research questions and improve their subsequent answers' contribution potential, we provide a set of genres for DSR research questions (Table 4), their profiles (Table 5), their evolution over DSR research's progress (Figure 4), and templates for common research projects (Table 6). On the one hand, these genres, profiles, and templates reveal DSR's diverse and dynamic nature, which contributes to positioning design science as a distinctive research paradigm (Rai, 2017). On the other hand, these aspects also reveal the territory claimed by design science in terms of research practice. Moreover, they provide hints that future DSR should either consolidate or expand its territory.

We also propose a typology highlighting how research questions are formulated in DSR. We hope that this typology will inspire DSR researchers to interpret, position, and structure their future research and their intended contributions. We suggest that the typology should be used dynamically. In particular, the combination of the typology and Hevner's three cycles allows researchers to identify "what the next research question is" over a DSR project's course. In this respect, DSR researchers can use the typology's basic forms, templates, and profiles to formulate the identified research questions. We would like to emphasize that we do not regard our research question genres, profiles, and templates as mandatory for DSR researchers.

In addition, it is also not mandatory for research questions constructed at the beginning of a DSR endeavor to remain invariant over time and, thus, limit the design and inquiry's scope. We understand that research questions may change during a DSR project, of which the current research is an example. We started with the initial question "How can we construct research questions in line with the DSR paradigm's nature and purpose?", which can now be split into four questions: 1) what prior knowledge is available about DSR research questions?; 2) how can we represent research questions that are in line with the DSR paradigm's nature and purpose?; 3) which components define research questions that are in line with the DSR

paradigm's nature and purpose?; and 4) what new knowledge is available about DSR research questions? These changes, again, fit the use of the research question genres in Hevner's cycles.

We hope that our investigations' results will guide and inspire DSR researchers to use research questions to help ensure that their research has a solid foundation (through problem-solving, gap-spotting, or problematization). In addition, research questions can help researchers consider the scope of their design and corresponding inquiry comprehensively to allow them to maximize their research contributions and their impacts. These recommendations apply at the outset of a new DSR endeavor and over its duration whenever the evaluation results call for a reconsideration of the artifacts beyond incremental redesigns, or even call for an entirely new research direction.

9 Conclusion

We analyze the existing DSR literature to understand DSR research questions' construction and formulation. We identify ways of constructing research questions and define particular question genres. These ways and genres can help researchers better understand prior research and construct their own research questions. We provide further guidance through a typology of research questions addressing common patterns to express research questions during a DSR project's progress. Although several principles of conducting and presenting DSR have already been presented (Gregor & Hevner, 2013; Hevner & Chatterjee, 2010), this study is a pioneer regarding providing specific guidelines on how to construct DSR research questions.

However, our research is not without its limitations. First, research questions have a key role in communicating the research after the conclusion of a project. Our findings should therefore be interpreted in light of what DSR is expected to deliver at the end of a project. In addition, a research project should not be over-rationalized at its very beginning. Second, the current research is based on research questions explicitly reported in DSR publications, which means implicit research questions may have been missed. Nevertheless, examining research questions documented in academic publications has been successfully used by others (Hällgren, 2012; Sandberg & Alvesson, 2011). Third, while we propose a typology based on the empirical analysis of 104 DSR publications, it needs to be further evaluated. As suggested by Prat et al. (2015), we plan to conduct both a formative and a summative evaluation in the future. Fourth, while our sample is of a reasonable size, we could extend the sample to include more dissertations, journals, and conferences. This would increase the generalizability of the research results, which will be the object of our future work. Finally, even though the topic that this research addresses is related to research philosophy and epistemology, we have not yet explored it from these perspectives.

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Appendix A: List of Reviewed publications

No	Reference
Mature publications (MIS Papers)	
1	Abbasi, A., & Chen, H. (2008). CyberGate: A Design Framework and System for Text Analysis of Computer-Mediated Communication. *MIS Quarterly*, *32*(4), 811–837.
2	Abbasi, A., Albrecht, C., Vance, A., & Hansen, J. (2012). MetaFraud: A Meta-Learning Framework for Detecting Financial Fraud. *MIS Quarterly*, *36*(4), 1293–1327.
3	Abbasi, A., Zhang, Z., Zimbra, D., Chen, H., & Nunamaker, J. (2010). Detecting Fake Websites: The Contribution of Statistical Learning Theory. *MIS Quarterly*, *34*(3), 435–461.
4	Adipat, B., Zhang, D., & Zhou, L. (2011). The Effects of Tree-View Based Presentation Adaptation on Model Web Browsing. *MIS Quarterly*, *35*(1), 99–121.
5	Adomavicius, G., Bockstedt, J., Gupta, A., & Kauffman, R. (2008). Making Sense of Technology Trends in the Information Technology Landscape: A Design Science Approach. *MIS Quarterly*, *32*(4), 779–809.
6	Chen, R., Sharman, R., Rao, R., & Upadhyaya, S. (2013). Data Model Development for Fire Related Extreme Events: An Activity Theory Approach. *MIS Quarterly*, *37*(1), 125–147.
7	Chou, C.-H., Zahedi, F., & Zhao, H. (2014). Ontology-Based Evaluation of Natural Disaster Management Websites: A Multistakeholder Perspective. *MIS Quarterly*, *38*(4), 997–1016.
8	Ketter, W., Peters, M., Collins, J., & Gupta, A. (2016). A multiagent competitive gaming platform to address societal challenges. *Mis Quarterly*, *40*(2), 447–460.
9	Larsen, K., & Bong, C. H. (2016). A tool for addressing construct identity in literature reviews and metaanalyses. *MIS Quarterly*, *40*(3), 529–551.
10	Lau, R., Liao, S., Wong, K. F., & Chiu, D. (2012). Web 2.0 Environmental Scanning and Adaptive Decision Support for Business Mergers and Acquisitions. *MIS Quarterly*, *36*(4), 1239–1268.
11	Lee, J., Wyner, G., & Pentland, B. (2008). Process Grammar as a Tool for Business Process Design. *MIS Quarterly*, *32*(4), 757–778.
12	Lin, Y.-K., Chen, H., Brown, R. A., Li, S.-H., & Yang, H.-J. (2017). Healthcare Predictive Analytics for Risk Profiling in Chronic Care: A Bayesian Multitask Learning Approach. *MIS Quarterly*, *41*(2), 473-495.
13	McLaren, T., Head, M., Yuan, Y., & Chan, Y. (2011). A Multilevel Model for Measuring Fit Between a Firm's Competitive Strategies and Information Systems Capabilities. *MIS Quarterly*, *35*(4), 909–929.
14	Parsons, J., & Wand, Y. (2008). Using Cognitive Principles to Guide Classification in Information Systems Modeling. *MIS Quarterly*, *32*(4), 839–868.
15	Pries-Heje, J., & Baskerville, R. L. (2008). The Design Theory Nexus. *MIS Quarterly*, *32*(4), 731–755.
16	Reinecke, K., & Bernstein, A. (2013). Knowing What a User Likes: A Design Science Approach to Interfaces that Automatically Adapt to Culture. *MIS Quarterly*, *37*(2), 427–453.
17	Sahoo, N., singh, param vir, & Mukhopadhyay, T. (2012). A Hidden Markov Model for Collaborative Filtering. *MIS Quarterly*, *36*(4), 1329–1356.
18	Thomas, D., & Bostrom, R. (2010). Vital Signs for Virtual Teams: An Empirically Developed Trigger Model for Technology Adaptation Interventions. *MIS Quarterly*, *34*(1), 115–142.
19	Vance, A., Lowry, P. B., & Eggett, D. (2015). Increasing Accountability Through User-Interface Design Artifacts: A New Approach to Addressing the Problem of Access-Policy Violations. *MIS Quarterly*, *39*(2), 345–366.
20	VanderMeer, D., Dutta, K., & Datta, A. (2012). A Cost-Based Database Request Distribution Technique for Online e-Commerce Applications. *MIS Quarterly*, *36*(2), 479–507.
21	Venkatesh, V., Aloysius, J. A., Hoehle, H., & Burton, S. (2017). Design and Evaluation of Auto-ID Enabled Shopping Assistance Artifacts in Customers' Mobile Phones: Two Retail Store Laboratory Experiments. *MIS Quarterly*, *41*(1).
Extensive publications (PhD Dissertations)	
22	Adams, R., 2012. The advanced data acquisition model (ADAM): a process model for digital forensic practice (Doctoral dissertation, Murdoch University).
23	Bauer, A., 2016. Information filtering in high velocity text streams using limited memory: an event-driven approach to text stream analysis (Doctoral dissertation, University of Regensburg).

24	Ducrou, A.J., 2009. Complete interoperability in healthcare: technical, semantic and process interoperability through ontology mapping and distributed enterprise integration techniques (Doctoral dissertation, University of Wollongong).
25	Finney, K.T., 2012. Ontology management and selection in re-use scenarios (Doctoral dissertation, University of Tasmania).
26	Fumarola, M., 2011. Multiple Worlds: A multi-actor simulation-based design method for logistics systems (Doctoral dissertation, Delft University of Technology).
27	Hanid, M.B., 2014. Design science research as an approach to develop conceptual solutions for improving cost management in construction (Doctoral dissertation, University of Salford).
28	Künzle, V., 2013. Object-aware process management (Doctoral dissertation, University of Ulm).
29	Löfström, T., 2015. On Effectively Creating Ensembles of Classifiers: Studies on Creation Strategies, Diversity and Predicting with Confidence (Doctoral dissertation, Stockholm University).
30	Marques, R.P.F., 2014. Organisational transactions with embedded control (Doctoral dissertation, University of Minho)
31	NARDI, J.C., 2014. A Commitment-Based Reference Ontology for Service: Harmonizing Service Perspectives (Doctoral dissertation, Federal University of Espírito Santo).
32	Niedermann, F., 2015. Deep Business Optimization: concepts and architecture for an analytical business process optimization platform (Doctoral dissertation, University of Stuttgart).
33	Osterwalder, A., 2004. The business model ontology: A proposition in a design science approach (Doctoral dissertation, University of Lausanne).
34	Pigott, D., 2012. A perspective and framework for the conceptual modelling of knowledge (Doctoral dissertation, Murdoch University).
35	Sapateiro, C.M.G.L.D., 2013. Evaluating mobile collaborative applications support of teamwork in critical incidents response management (Doctoral dissertation, University of Lisbon).
36	Scherer, S., 2016. Towards an E-Participation Architecture Framework (EPArt-Framework) (Doctoral dissertation, University of Koblenz-Landau).
37	Simoes, D. An End User Approach to Business Process Modelling (Doctoral dissertation, University of Lisbon).
38	Vanderfeesten, I., 2009. Product-based design and support of workflow processes (Doctoral dissertation, Eindhoven University of Technology).
39	Viberg, O., 2015. Design and use of mobile technology in distance language education: Matching learning practices with technologies-in-practice (Doctoral dissertation, Örebro University).
40	Wikström, R., 2014. Fuzzy ontology for knowledge mobilisation and decision support (Doctoral dissertation, Åbo Akademi University).
41	Zoet, M.M., 2014. *Methods and Concepts for Business Rules Management* (Doctoral dissertation, Utrecht University).
Emerging publications (Conference papers)	
42	Akoka, J., Comyn-Wattiau, I., Prat, N., & Storey, V. C. (2017). Evaluating Knowledge Types in Design Science Research: An Integrated Framework. In *Designing the Digital Transformation* (pp. 201–217). Springer, Cham.
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