Analyzing Design Knowledge Representation in Design Science Research and Deriving Recommendations to Support Design Knowledge Codification

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Abstract. The goal of design science research is the generation of novel artifacts. Thereby DSR projects generate valuable design knowledge, thus, underscoring the importance to codify of design knowledge for achieving scientific progress. The research community observes that DSR projects generate a large amount of design knowledge, but the developed knowledge often ends as a single success story. To counter this situation, we analyze the variety of design knowledge representation forms that have been published in the AIS Senior Scholars' Basket in design science research papers. Based on our systematic literature review, we identify prevalent ways of design knowledge representations. We provide as a central contribution how to effectively communicate design knowledge through the derivation of recommendations that provides practical guidance to support researchers and practitioners in making design knowledge contributions reusable and applicable.

Keywords: Design knowledge · Codification · Design science research

1 Introduction

Design science research (DSR) offers an important paradigm for conducting applicable and rigorous research to real-world design problems [1]. Therefore, DSR aims to generate prescriptive knowledge about the design of information systems (IS) artifacts [2], oftentimes supported through well-cited DSR approaches for conducting DSR projects such as the three cycle view of Hevner [3] and the DSR process by Peffers et al. [1]. The overall "*goal of DSR is to generate knowledge on how to build effectively innovative solutions to important problems*" ([4], p.15) by finding solutions (solution-space) for design problems (problem-space) [4]. The generated design knowledge can be represented in different forms such as design patterns, design principles, design theories, and design artifacts [4, 5]. Typically, a design project has two outcomes – an artifact and a design theory [6], the latter summarizes knowledge on how to design the artifact [7].

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Although, the approaches by Peffers et al. [1] and Hevner [3] aim to provide guidance on how to conduct, evaluate, and present design science research, the DSR community observes that the projects neglect the transfer of generated design knowledge. DSR projects may produce artifacts and theories that are rarely reused [5, 6]. Thus, design knowledge is often lost at the end of the projects and buried in digital libraries of conference proceedings and journals [6]. The limited design knowledge reusability in the IS community is problematic, as single contributions tend to remain isolated with little to no relation to other solutions [5]. This is accompanied by the problem that valuable knowledge is lost, although it could be useful in new projects, thus, hindering the progress of science. The lack of reuse also brings with it that the generated design knowledge does not leap from research into practice [8].

An important reason that makes design knowledge difficult to share and accumulate is the fact that design knowledge has certain characteristics and abstraction levels, especially if it is not represented in a codified form [9, 10]. To counter this situation, we review the variety of design knowledge representation forms that have been published in the AIS Senior Scholars' Basket. With our paper, we aim to provide a holistic picture of different DSR codification forms. Therefore, we investigate how DSR papers share generated design knowledge in IS journals and draw conclusions on how to codify design knowledge by answering the following research question.

RQ: How is design knowledge represented in design science research papers in leading IS journals?

To answer our research question, we first conduct a systematic literature review following vom Brocke et al. [11] and Webster & Watson [12] to identify DSR papers that conduct DSR in IS journals. Second, we analyze how design knowledge is represented in extant literature. Afterwards, we draw conclusions regarding associations between knowledge generation, purpose, and representation forms to provide guidance on how to facilitate design knowledge accumulation for reuse by deriving recommendations based on our review.

2 Theoretical Background

2.1 Design Science Research and the Importance of Design Knowledge

We first want to go deeper into the design science research paradigm and analyze the meaning of accumulating and codifying design knowledge. In the last decades, design science research became an established and widely used research method in information systems research [13]. DSR provides a structure for constructing artifacts [10] and it oftentimes follows process methods [13, 24] to bring the practical development of artifacts into IS research. The outcome of DSR projects is typically two-fold: design artifacts and design theories [10, 14]. Thus, resulting in a large range of DSR projects with different design outcomes. Not only does the application field of DSR vary but also how authors apply and ultimately present DSR [13]. Conducting DSR oftentimes means solving design problems by developing and evaluating artifacts with the help of applying concepts, such as (design) theories and design principles, to map and support design processes [1].

One thing all DSR projects have in common is the generation of valuable and novel design knowledge [15]. As Peffers et al. [1] recommend in their DSR guidelines, the communication of the design outcomes is one important part of the overall project. DSR projects accumulate design knowledge through building, testing, and extending artifacts across projects and publications [10]. The accumulation and codification of knowledge is the essence of theories and knowledge sharing [5]. Gregor et al. [10] remark on the importance of design knowledge codification to make design science formalizable through design theories.

Design knowledge is one specialized part of knowledge, namely knowledge to design an artifact including used methods and constructs to design the artifact [10]. The knowledge literature contrasts different types of knowledge, such as tacit and explicit knowledge [16], which impact a person's ability to codify knowledge [17]. Design knowledge is a special form of knowledge, namely knowledge to design a system including methods and constructs [10]. While explicit knowledge can be easily transferred, other types of knowledge (such as tacit knowledge) are difficult to transfer [9]. Typically, knowledge is developed by an individual [16] through applying previous knowledge in new contexts. Van Aken defines design knowledge as *"[…] knowledge that can be used to produce designs. The general design knowledge in the repertoire of the senior designer is compiled by him/ her over the years through formal education and through learning on the job"* ([18], p. 9).

2.2 Design Knowledge Accumulation to Facilitate Reuse

As DSR establishes its position as an important part of IS research, more and more researchers are pointing out the importance of design knowledge accumulation and codification [4, 19]. Numerous scholars, such as vom Brocke et al. (2019) and Rai (2017), call for approaches that effectively deal with the accumulation and codification of design knowledge in DSR in high-caliber IS journals [5].

To counter the problem, recent literature, for example, by Chandra Kruse and Nickerson [5], analyzed the essence of design in-depth and derived key design elements to facilitate design knowledge accumulation. Vom Brocke et al. [4] provide a framework on how to position design knowledge contribution in problem and solution space by providing a set of principles that facilitate knowledge accumulation. Other research, such as the design knowledge typology by Müller and Thoring [9] or the design knowledge taxonomy by Dickhaut et al. [15] provide frameworks to conceptualize design knowledge and facilitate the understanding of design knowledge properties.

To understand how design knowledge is actually reused in practice, Chandra Kruse et al. [20] analyze the reuse of design principles with practitioners. Schoormann et al. [21] look at the reusability of design principles in the literature. However, the literature still lacks an analysis of the different ways in which design knowledge is represented to understand how design knowledge has been codified for dissemination in design science research so far. Thus, the goal of our paper is to analyze how previous design science projects codify their generated design knowledge through published papers.

3 Identifying and Classifying Design Knowledge Representation Forms

3.1 Systematic Literature Review

In the following, we describe our literature search process that provides the empirical basis for our analysis. Furthermore, we explain the data analysis techniques used in this paper to analyze how previous DSR journal papers codify design knowledge.

We conducted a systematic literature analysis according to vom Brocke et al. [11] and Webster & Watson [12] to identify the literature foundation of our paper. The goal of our systematic literature is to identify papers that conduct DSR methods and are published in the AIS Senior Scholars' Basket: Management Information Systems Quarterly (MISQ), Journal of Management Information Systems (JMIS), Journal of the Association for Information Systems (JAIS), Information Systems Research (ISR), European Journal of Information Systems (EJIS), Information Systems Journal (ISJ), Journal of Strategic Information Systems (JSIS), Journal of Information Technology (JIT). We focus on high published DSR papers because most conference papers examine a small part of big design science projects. In addition, we see the highest potential to learn how to codify design knowledge in a useful way from high published journal papers. Reasons such as long and hard review iterations force the author team to carefully make their acquired design knowledge available.

Table 1. Overview of searched journals.

Outlets	Total hits	Relevant hits
Management Information Systems Quarterly (MISQ)	121	18
Journal of Management Information Systems (JMIS)	85	26
Journal of the Association for Information Systems (JAIS)	114	34
Information Systems Research (ISR)	50	6
European Journal of Information Systems (EJIS)	115	24
Information Systems Journal (ISJ)	60	4
Journal of Strategic Information Systems (JSIS)	24	2
Journal of Information Technology (JIT)	52	1
Sum	**621**	**115**

To cover a broad set of publications, we use the keywords "design science" in the databases. Table 1 provides an overview of the results. The initial number of 621 papers was reduced by reading the papers' title, abstracts, and keywords. We reduced the literature by eliminating papers that are out of our scope such as papers that dealt with design science research from a conceptual or methodological viewpoint. Resulting in a selection of 115 papers, that are relevant for our following analysis.

The 115 relevant papers were analyzed following an iterative process aggregating the insights. The iterative process was started by two of the researchers who independently code a subset of 5 randomly chosen articles. Next, we re-examined the original subset and analyzed variations in coding. We proceeded iteratively with the coding until all 115 papers were independently coded.

3.2 Coding Frame

We use a theoretical frame to analyze the resulting 115 papers regarding design knowledge representation. The coding frame is based on literature on DSR and design knowledge generation or codification. In the following, we present the underlying theoretical understanding to be as transparent as possible during our analysis. In general, our coding frame is based on the essay by Gregor and Hevner to positioning and presenting design science research [22], Nonaka's knowledge creation theory [16], and vom Brocke et al.'s guidance on how to accumulate design knowledge [4].

The generation of design knowledge takes place in a variety of ways, which is an important characteristic to understand its nature. So design knowledge may be generated with the goal to develop *principles of form and function* [23], by developing an *instantiated implementation* [23], developing a *prototypical design* [24], through the development of a *method* [25], or by developing *models* [26, 27].

We describe below how we classify the design outcomes and give examples for each cluster. *Principles of form and function* describe the design of artifacts generally and provide instructions on how to design those elements. A lot of design science research papers develop design principles which we classify as one example of principles of form and function.

Papers that develop programs or high-fidelity systems are classified *as instantiated implementation* while mock-ups, prototypes, or low-fidelity programs are coded as *prototypical design*. We distinguish instantiated implementation from prototypes by the degree of completion. While prototypes are developed exemplarily for evaluation or demonstration, instantiated implementation can actually come to use.

DSR papers that provide step-by-step instructions and provide users concrete directions to do something are classified as *method* development. A more formal artifact output is the development of models to understand or explain occurrences. Thus, the design knowledge origin represents our first coding frame to understand design knowledge representation forms. We use the frame as a mapping to analyze differences between different design science research artifacts. Our second coding frame is related to the level of abstraction. Thus, knowledge may be context-specific, which is often the case if the knowledge is less abstracted and applied in one specific case [16]. If design knowledge is abstract and applicable in many cases, there are few in-depth details.

To go more in detail, our third coding frame focus on the knowledge expression level. We distinguish tacit, explicitly articulated, and explicitly codified design knowledge [16]. Tacit knowledge is not represented or hardly represented at all. This makes the knowledge hard to grasp. The codification of design knowledge may occur in different forms. Structured text-based codification approaches focus on codification in texts, mostly as highlighted key points of structured lists. Another clear presentation form are tables. Prototypes or screenshots are often used to provide graphic visual support.

DSR papers that use no structured codification form are summed up as unstructured. Our last coding frame focuses on the main formulation and distinguishes descriptive and prescriptive design knowledge which is often used as a key indicator to analyze the knowledge reuse potential [21, 28].

4 Results: Status Quo of Design Knowledge Representation in Design Science Research

While design science research has been around for 30 years, its application and the knowledge codification in the IS discipline are very different. Our literature analysis revealed several insights, which we present in the following. We use the insights to derive recommendations on how to get the maximum out of design science research and how to improve design knowledge re-use. The use of design science research differs regarding the research outcome within the outlets (see Table 2).

Table 2. Overview of artifact outcome.

	MISQ	JMIS	JAIS	ISR	EJIS	JIT	ISJ	JSIS	Sum
Principles of form and function	12	5	24	2	15	0	3	1	**62**
Instantiated implementation	9	2	6	0	1	0	0	0	**18**
Prototypical design	5	10	12	0	8	1	1	0	**37**
Methods	4	6	7	2	2	1	0	2	**24**
Model	4	9	2	2	1	0	1	0	**19**

Thus, a major part of the DSR papers develop principles of form and function, namely 62 papers. Some of these papers combine the development of an artifact such as an instantiated implementation together with a prototypical design. Here, the design object supports the practical evaluation of the principles. Most of the papers provide a general overview of knowledge from the solution-space, knowledge from the problem-space, process knowledge, and object knowledge. The principles of form and function papers focus on providing process knowledge and design knowledge from the problem-space (see Table 3). Most of the codified design knowledge is generally applicable resulting in more abstract knowledge. The principles of form and function papers in our analysis use primary text-based codification forms such as highlighting the knowledge through marking the knowledge bold to provide the information in a clear way.

We identified only 18 papers whose outcomes are instantiated implementations. Our analysis demonstrates that the papers differ in their way of presenting design knowledge, especially in the integration of visual representations and the inclusion of problem knowledge. Almost all papers present the knowledge behind the problem space and integrate screenshots or graphical representations. Only a few papers develop context-specific design knowledge and most of the papers integrate generally applicable knowledge by abstracting their key findings.

Table 3. Design knowledge representation.

	Principles of form and function	Instantiated implementation	Prototypical design	Methods	Model
Unit of design					
Object knowledge	◑	◑	◕	◑	◑
Process knowledge	◕	◕	◕	●	◕
Problem-space knowledge	◕	●	◕	●	◕
Solution-space knowledge	◑	◑	◑	◕	◑
Level of abstraction					
Context specific	◔	◔	◑	◔	◕
Generally applicable	◕	◑	◑	◕	◔
Knowledge representation					
Tacit	○	○	○	○	○
Explicitly articulated	◑	◔	◑	◔	◑
Explicitly codified	◑	◑	◑	◕	◑
Codification format					
Structured text- based	●	●	●	●	●
Structured tabular	◔	○	◔	◔	◔
Graphic visual	◑	◕	◕	◑	◕
Unstructured	○	○	○	○	○
Main formulation					
Descriptive knowledge	◑	◑	◕	◔	◕
Prescriptive knowledge	◑	◑	◑	◕	◔
Legend	High ●	Rather high ◕	Moderate ◑	Rather low ◔	Low ○

We classify 37 papers whose design outcomes are prototypical designs. The prototypical design papers differ little from those that develop an instantiated implementation. As a rule, these papers clarify very well how the design process has proceeded and define the knowledge through process knowledge. Many of the papers combine descriptive and prescriptive knowledge which comes from describing the artifacts developed. In addition, another way to use DSR is the development of a method to provide step-by-step guidance. In our analysis, the development of a method is the goal of 24 papers in our analysis. The papers that develop methods clearly distinguish themselves from the other papers by providing detailed guidance. This is also shown by the fact that these papers primarily use prescriptive design knowledge and thus convey precise design information.

In our analysis, 19 papers' outcomes are models. In contrast to the primarily used, prescriptive design knowledge are the papers whose outcomes are models. Here, mainly descriptive design knowledge is presented. However, the papers rather use a visual representation to convey their artifact.

5 Critical Discussion of the Status Quo and Recommendations

In the following, we will discuss the status quo of design knowledge codification and provide recommendations for moving our field further in codifying and accumulating design knowledge. We illustrate our recommendations with examples from prior research, although we note that the selected papers are just examples.

As seen in our analysis (Sect. 4) principles of form and function are a common way to codify design knowledge. Principles of form and function can be represented in different ways. In addition to the visual highlighting – specially marked or listed in a table – the expression differs in the use of descriptive and prescriptive knowledge. Chandra Kruse et al. [29] propose a formulation approach of design principles that is clear and precise. We would like to highlight the paper from Recker [30] as one illustrative example to provide precise design knowledge and equally shows how the developed design principles are anchored in the solution-space and problem-space. In the paper, the author develops design principles to improve the state-tracking ability of covid-19 dashboards. Thereby the design principles are not only developed and presented but also related to the underlying "aim, mechanism, and rationale of the design principle" by providing a clearly arranged overview in which the developed design principles are set in relation to their design objective. Thus, the author provide knowledge on how the problem-space by presenting the theoretical foundation together with the application field (object knowledge) and the mechanisms to achieve the design, leading to the first recommendation:

Recommendation 1: *Include aim, mechanism, and rationale of the design knowledge.*

Papers that develop principles of form and function combine the text-based representation with graphic visual details. An illustrative example is Seidel et al. [31], who develop design principles for systems that support organizational sensemaking in environmental sustainability transformations. In their paper, the authors use a clearly arranged form to provide text-based design knowledge and demonstrate the design of their principles through various graphics and artifact screenshots. A combination of structured text-based knowledge and graphic-visual insights achieves a transfer to the practical implementation, which makes the knowledge very specific but still generally applicable through more abstract design principles.

Recommendation 2: *Support abstract principles of form and function by providing specific design applications through graphic-visual details.*

The report of an instantiated implementation is difficult because a running program must be described as comprehensibly as possible but mostly text based. Representations, such as the description of the system architecture or the interface challenge the authors. One paper that we would like to highlight here is the paper by Nguyen et al. [32] who develop a learning analytic system. In their paper, the authors derive design principles, which they then specify in more detail for the application field and develop a learning analytics system. To meet the challenge of providing insights into the developed technology the authors include a visual presentation of the underlying architecture. Thus, they communicate architectural design knowledge related to the actual implementation.

Recommendation 3: *Include detailed sketches of your system architecture to provide system insights.*

The papers that develop prototypes demonstrate process knowledge can be communicated in an application-oriented manner. We would like to reference the paper from Meth et. al [33] who propose a design theory for requirement mining systems. The authors solve the challenge that the prototype cannot be presented through text by integrating a screenshot and enriching it with further explanations. To demonstrate the functionalities and technology, the authors use a process-oriented figure. The figure visualizes how the individual stakeholders in the system interact with each other.

Recommendation 4: *Provide insights into the technology use through process-oriented figures.*

DSR projects are often conducted over a long period of time and include several crucial events that contain valuable knowledge. In most cases, project findings are less codified on an ongoing way but tend to be codified toward the end of the project. To get around this, design journeys or evolution graphics on how design knowledge unfolds through multiple revisions are helpful. They provide an overview of the course of the project and prevent design knowledge from being lost [8]. Design science tool support approaches can also provide valuable guidance as for example the "MyDesignProcess" tool [34]. A good example to demonstrate design evolutions is the paper from Widjaja et al. [35] who visualize their design evolution and go into detail about their individual five design artifacts and their progress. This makes it possible to see the entire development process and understand how individual components are interlocked with each other.

Recommendation 5: *Use design journeys or evolution figures to accumulate as much design knowledge as possible.*

6 Conclusion and Future Research Directions

The aim of our paper is to analyze design knowledge representation in design science research papers and to derive recommendations to codify developed design knowledge in a rich, reusable way. To answer our research question, we conducted a systematic literature review and analyzed all papers in the AIS basket of eight that perform DSR.

Our results show how different the design artifact is as a DSR project outcome, but also within the comparison of the artifacts the papers differ in their way of presentation. Our observations confirm the findings of previous literature. For example, the degree of abstraction of codification varies greatly by design outcome, which is consistent with the findings of Wache et al. [36].

Design principles papers often follow the formulation guidelines of Chandra Kruse et al. [19] and thus generate prescriptive design knowledge. With the derivation of our five recommendations, we provide researchers and practitioners with guidance on how to improve the codification of design knowledge. The recommendations are based on our literature review and offer scope for further research. For example, further research can address the evaluation of these recommendations or further elaborate them into a framework for codifying applicable reusable design knowledge.

Due to our search string "design science" we cover a large part of design papers but there are a vast of papers that design artifacts but use another term such as action design research [37]. Further research could use these search strings and extend the search to other design disciplines such as human-computer interaction, computer science or specific conferences such as DESRIST and analyze how they codify design knowledge. Our analysis focus on journal papers could lead to a possible bias of editorial policies in these journals which often forces design science researchers to submit their research to design-related journals or conferences [38]. Overall, we provide a foundation for the discussion on how to codify reusable and applicable design knowledge.

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