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## Knowledge Contributions in Design Science Research: Paths of Knowledge Types

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### Abstract

Design science research addresses important, complex real-world problems. Although well-accepted as part of research in information systems, initiating or progressing a design science research project still requires effort to describe how knowledge creation emerges and its underlying dynamics. Given the existing body of knowledge on design science research, it should be possible to learn from that knowledge to progress future work. This paper analyzes design science research projects to identify and make explicit their knowledge contributions while recognizing the plurality of a project's knowledge contributions with respect to a project's knowledge scope and knowledge goals. The construct of a *path of knowledge types* is introduced that represents how knowledge contributions are dynamically created throughout a project. These paths form the basis for the derivation of seven design science research strategies, which lead to guidelines for initiating or progressing a project. This effort is compared to other research that analyzes the growing body of work in design science with respect to knowledge contributions and project classifications.

**Keywords:** Design science research, knowledge contribution, path of knowledge types, design science research strategy, knowledge goal, knowledge scope, design science research guidelines

## 1 Introduction

Design science research (DSR) creates innovative artifacts to solve complex, real-world problems and generate design knowledge. Much effort has gone into producing and reporting many diverse types of knowledge contributions across a large variety of application domains. It should be helpful to analyze the nature of existing contributions to appreciate how researchers produced them to both progress our understanding of design science research and provide helpful guidelines for carrying out future research. Doing so requires some way to represent and organize existing knowledge contributions, while acknowledging that design science research is dynamic, pluralistic and contextual [20]. A DSR study has *knowledge moments* or different points in time that occur throughout a project that have different assumptions and methods, making the research process dynamic [9]. Researchers could recognize how to contribute new knowledge while using, combining, and extending what has been learned from existing work. We, thus, propose the following research questions.

*RQ1*: How can we represent the contributions of design science research, recognizing its dynamic, pluralistic, and contextual nature?

*RQ2*: How can we characterize, and learn from, representative knowledge contributions in prior research and classify them into useful strategies for future projects?

*RQ3*: What strategies can guide researchers in the beginning of, or throughout, a project, so their knowledge contributions can be identified and developed?

The objective of this research is to identify and formalize knowledge contributions in design science in such a way that it represents the body of work that exists and provides insights into how researchers can conduct future projects. We first introduce a *path of knowledge types* construct to represent the knowledge contributions of DSR projects. The paths are grouped into categories that form the basis for seven research strategies. From these strategies, we derive guidelines for initiating and developing design science research projects.

This paper makes several contributions. First, it introduces the construct of a path of knowledge types. Second, it generates research strategies and guidelines that capture the dynamic and pluralistic

nature of DSR knowledge that have often been overlooked. Together, they provide a way to progress our understanding of DSR knowledge contributions based on an analysis of successful projects, which can then be used by researchers to initiate, develop, and articulate their own knowledge contributions. Third, our research questions align with identified needed future research [66]: representation languages for problem and solution descriptions (RQ1); classification of problems and solutions (RQ2); and methodological guidance (RQ3), providing a practical perspective.

Section 2 reviews related work. Section 3 presents our methodology and the construct of a path of knowledge types. Section 4 details the steps followed to define strategies and derive guidelines for conducting further research. Section 5 discusses the implications and section 6 concludes the paper.

## 2 Related Research

Figure 1 shows the progression of design science research through a set of eras, noting influential works as found in journal and prominent conference publications.<sup>1</sup>

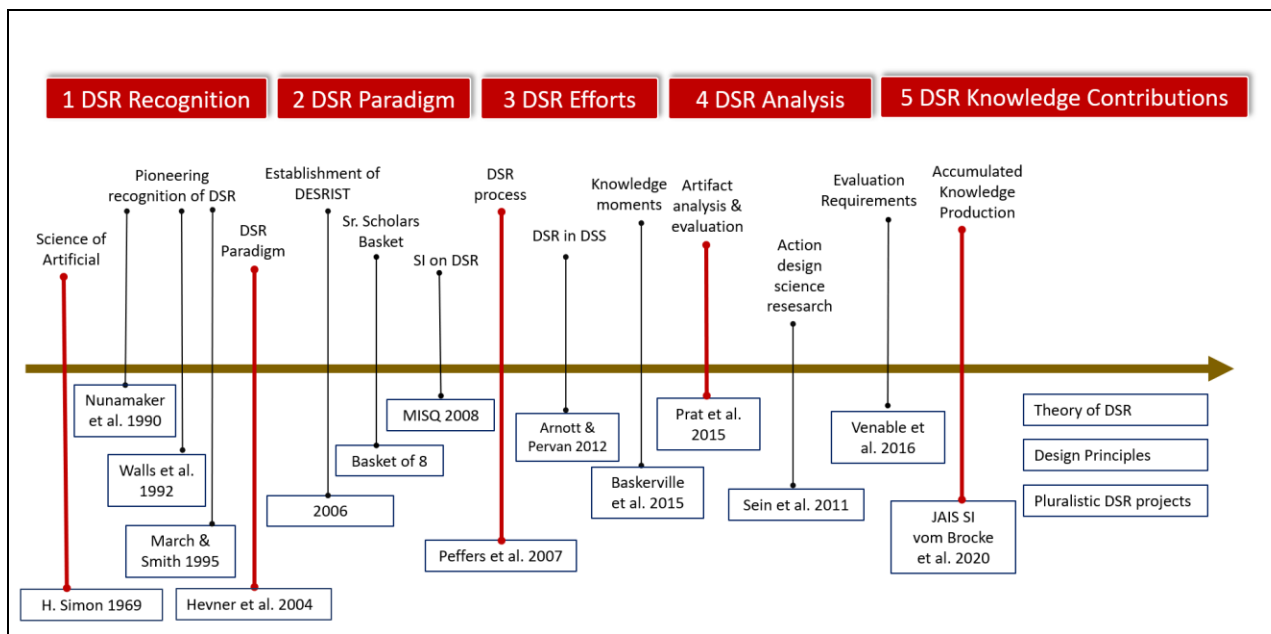


Figure 1. Progression of design science research eras

<sup>1</sup> An era is a recognized stage of development (<https://www.merriam-webster.com/dictionary/era>).

Simon's [61] *Science of the Artificial* inspired design science research, which now has methodologies and evaluation guidance and recognizes different types of knowledge related to design and to science [62]. Nunamaker et al. [48] presented information systems development as a research methodology. Walls et al. [67] made an initial attempt to formalize DSR, followed by March and Smith [41] and Hevner et al. [29], who note the importance of design science in decision support. Hevner et al. [29]. Gregor and Hevner [23] proposed initial guidelines. Diverse artifacts appear in socio-technical systems, for which design science is needed [27]. Arnott and Pervan [3, 4] argue that design science research provides a way to improve decision support. Other notable efforts include Sein et al. [59] on action design research. Attempts to establish DSR as a paradigm included a special issue in *MIS Quarterly* [42] and a methods publication [53]. The eras progressed to include the development of many DSR artifacts [54] and topics such as: evaluation [64]; frameworks [65]; design principles [25]; context and projectability [12]; creativity [10]; innovation [28]; design logic [11]; and resources [30].

Efforts to organize the vast literature on design science research analyze the research conducted throughout these eras [20, 31, 40, 56, 58]. However, these efforts mainly overlook the dynamic and pluralistic nature that is inherent in the wicked problems addressed by design science research. We attempt to do so by concentrating on a project's knowledge goals and knowledge scope, acknowledging that design knowledge may be dependent upon its context.

## 2.1 Knowledge Contributions

Three main dichotomies characterize knowledge contributions. The first, *knowledge goal*, differentiates between design and science [9]. The purpose of design is prescriptive; science is descriptive, explanatory, or predictive. The second, *knowledge scope*, contrasts abstract artifacts with material artifacts or instantiations [24]. The knowledge scope can be nomothetic or idiographic. Idiographic is a study of a particular case; nomothetic refers to general theories or concepts for an entire set of classes [9]. The third dichotomy originates from two views of knowledge contributions: artifacts and design theories.

Hevner et al. [29] identify contributions as abstract artifacts (constructs, models, methods) or instantiations [41]. Eierman et al. [19] relate Simon's work [61] to a set of broad decision support constructs. Walls et al. [67] state that DSR should produce *design theories*, with kernel theories, meta-requirements, meta-design, and testable hypotheses. Gregor and Hevner [23] distinguish prescriptive ( $\Lambda$ ) and descriptive knowledge ( $\Omega$ ). Of the three dichotomies, knowledge goal (design versus science) and knowledge scope (nomothetic versus idiographic) can be combined in multiple ways, leading to diversity in knowledge contributions. The dichotomy between artifact and design theory relates to knowledge scope and knowledge goal. Design theories include both science and design knowledge.

Although the three dichotomies reflect the diversity of knowledge contributions, they do not account for the dynamic nature of knowledge production. This can be captured explicitly by recognizing the plurality of knowledge production and by distinguishing knowledge goals (design or science) and knowledge scope (idiographic or nomothetic). A DSR study has *knowledge moments*, through which it might pass on its way to completion, which makes the research process dynamic [9]. Akoka et al. [1] propose the concept of a *knowledge path*, to represent the knowledge contribution of a single project as a succession of knowledge moments, characterized by a knowledge goal and a knowledge scope. The PDSA framework [7] has two dimensions: knowledge goal (prescriptive (P) or descriptive (D)) and knowledge scope (situated (idiographic) (S) or abstract (nomothetic) (A)), but does not accommodate all of the knowledge types of Johannesson and Perjons [32]. Rothe et al. [56] study the accumulation of design knowledge dimensions of goal and scope to identify patterns of knowledge creation mechanisms without proposing guidelines for developing contributions.

Herwix and Rosenkranz [26] propose a framework based on knowledge goals and scope. They conclude that design science and behavioral science research are increasingly intertwined, so more fine-grained and meta-paradigmatic models are needed. They distinguish knowledge production episodes (similarly to knowledge moments), but not dynamic sequencing. Drechsler and Hevner [18] identify six modes of design theorizing, which capture some dynamics of knowledge production. Vom

Brocke et al. [66] focus on the evolution of design knowledge based on: projectability, fitness, and confidence, with coarse-grained knowledge maps to illustrate knowledge accumulation in projects.

Existing characterizations and representations of knowledge contributions only partly capture the diversity of knowledge types and either ignore the dynamics of their combinations, or are too coarse-grained. We account for the diversity of knowledge types and provide a way to represent the combinations at a fine-grained level of detail. Doing so enables us to identify strategies and guidelines for initiating and developing further contributions in DSR projects.

## **2.2 Other Contributions and Research Gap**

Other characteristics that might be important for classifying DSR include: context (including types of problems addressed), processes (e.g. [53]), methodologies for artifact building (e.g., action research [59]), evaluation [54, 64], resources [30], and categories [30, 32]. Iivari [30] proposes two categories, he calls strategies. In strategy 1, a researcher constructs an IT meta-artifact, possibly followed by an instantiation. In strategy 2, a researcher builds a concrete IT artifact to solve a specific problem, from which the researcher distils general knowledge (e.g., design principles). The strategies are contrasted along sixteen dimensions pertaining to the context, outcomes, process, and resource requirements, which are the most exhaustive for identifying classification criteria. Other categorizations of DSR are conceptual or based on selected publications; e.g., a typology of artifacts [54] or research gaps [5].

Although the types of artifacts or knowledge contributions are used to distinguish categories of research, the relationships between the categories and contributions are often unclear. We thus propose an empirical approach that: 1) analyzes published research, characterizes the research contributions as paths of knowledge types; 2) classifies knowledge contributions into categories that lead to research strategies; and 3) proposes guidelines that design science researchers can use in their knowledge production. In doing so, we extend the concept of knowledge paths [1] to account for the variety of knowledge types found in design science research.

### 3 Research Methodology

This research explicitly recognizes the pluralistic and dynamic nature of design science research. We take an empirical approach to identify, extract, and organize common forms of knowledge contributions to derive research strategies and guidelines. The two important dualities found in the centrality of knowledge for design science research are knowledge goals and knowledge scope, which help to explain the pluralism [47]. The main terms are first described in Table 1.

Table 1. Description of Terms

<b>Knowledge type:</b> DSR Knowledge as characterized by its scope and goal [1].
Knowledge scope: Level of generality of the knowledge: nomothetic (general theories or concepts that cover an entire set of classes) or idiographic (specific concepts for the problem setting and a potential artifact) [9].
Knowledge goal: Primary goal of knowledge produced; “what the [knowledge] is for” [22]; may be for analyzing, explaining, predicting, prescribing.
Definitional knowledge: concepts required to express knowledge in other categories (descriptive, explanatory, predictive, explanatory and predictive, prescriptive) [32].
Descriptive knowledge: “what is” [22, 32].
Explanatory knowledge: “how” and “why” things happened [22].
Predictive knowledge: what will happen if preconditions hold, with no causal explanations [22].
Explanatory and predictive knowledge (together): what will happen if preconditions hold and provide causal explanations [22].
Prescriptive knowledge: how something should be done [22].
<b>Knowledge moment:</b> episode of knowledge production, characterized by scope and goal [9], viewed in multiple ways: scientific pluralism [34].
<b>Knowledge path:</b> a chronological ordered set of knowledge types [1].
<b>Path of knowledge types</b> (as defined in this paper): Succession of knowledge moments in a DSR project, represented by a directed graph. Graph nodes represent knowledge moments. Edge labels make explicit the semantics of the links between each knowledge moment and its successor. Paths of knowledge types capture the dynamic and pluralistic nature of DSR.

#### 3.1 Research Overview

We use both knowledge goals and knowledge scope to identify the types of knowledge that emerge as an artifact develops over time. For research questions, *RQ1* (represent knowledge contributions), we enrich the knowledge paths of Akoka et al. [1] to propose a *path of knowledge types* construct that captures the dynamic nature of knowledge contributions.<sup>2</sup> For *RQ2* (identify and characterize

<sup>2</sup> We use the term “construct” according to a generally accepted typology of artifacts: constructs, models, methods, and instantiations. This term has slightly different meanings for design science and behavioral science. The meaning used in design science complies with the general definition: “A construct derives its name from the fact that it is a mental construction, derived from the general scientific process... Any given construct derives its scientific value from the shared meaning it represents for different people.” <https://www.britanica.com/science/construct>. Accessed 27 August 2022. We thank an anonymous reviewer for encouraging us to consider this term.



knowledge contributions), we use this construct to conduct a descriptive literature review classifying DSR studies into categories, from which we define a set of research strategies. For *RQ3* (provide guidelines), we build on the strategies to propose *guidelines* to initiate or conduct a DSR project. Figure 2 provides an overview of the steps followed in this research.

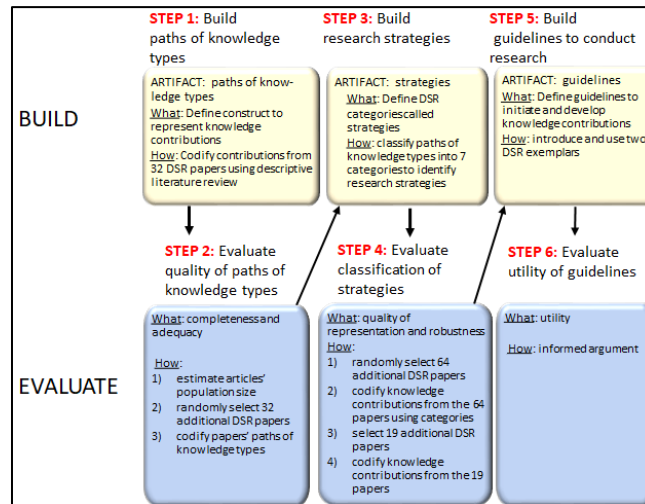


Figure 2. Research Approach (based on build-and-evaluate [32])

### 3.2 Path of Knowledge Types

The production of knowledge contributions in DSR is dynamic and pluralistic. The pluralism is reflected in the notion of *knowledge moments* through which a study might pass on its way to completion, with each knowledge moment creating its own contribution [9]. Identifying this progression and understanding its implications can point out useful ways to acknowledge and leverage these dynamic contributions, provided there is a way to do so. We accomplish this by deriving a set of guidelines. Pluralistic knowledge production is determined by the knowledge scope of *nomothetic* (general) versus *idiographic* (specific) [9, 47] and by knowledge goals, which can be *definitional*, *descriptive*, *explanatory*, *predictive*, or *prescriptive* [32]. (Although there is some debate over whether true nomothetic knowledge contributions exists, this distinction appears in the literature ([9, 15]). The *knowledge types*

obtained from considering both the scope and goals are shown in Table 2 and form the basis from which we categorize design science research contributions.

Table 2: Knowledge Types in Design Science Research

Knowledge Scope	Knowledge Goal	Knowledge Type
Nomothetic (general theories)	definitional	nomothetic definitional ( <i>N Def</i> )
	descriptive	nomothetic descriptive ( <i>N Desc</i> )
	explanatory	nomothetic explanatory ( <i>N Expl</i> )
	predictive	nomothetic predictive ( <i>N Pred</i> )
	explanatory and predictive (combined)	nomothetic explanatory and predictive ( <i>N Expl&amp;Pred</i> )
Idiographic (specific cases)	prescriptive	nomothetic prescriptive ( <i>N Presc</i> )
	descriptive	idiographic descriptive ( <i>I Desc</i> )
	explanatory	idiographic explanatory ( <i>I Expl</i> )
	predictive	idiographic predictive ( <i>I Pred</i> )
	explanatory and predictive (combined)	idiographic explanatory and predictive ( <i>I Expl&amp;Pred</i> )
	prescriptive	idiographic prescriptive ( <i>I Presc</i> )

The dynamic part is captured through successive knowledge moments, which can be represented by a *knowledge path* [1]. Table 3 shows how to represent and interpret a knowledge path from general (nomothetic) knowledge that is prescriptive to specific (idiographic) prescriptive knowledge.

Table 3. Knowledge Path: Progression from Nomothetic Prescriptive to Idiographic Prescriptive

Knowledge path	N Presc → I Presc
Interpretation	Nomothetic prescriptive knowledge progressing to idiographic prescriptive knowledge
Example	Risks to effective knowledge sharing in agile software teams: A model for assessing and mitigating risks by Ghobadi and Mathiasen [21]
Nomothetic prescriptive knowledge	Model of assess a project's risk profile and identify a resolution strategy
Idiographic prescriptive knowledge	Applied model to one software company and evaluated its utility.
Path of knowledge type	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$ Risk model (N Presc) applied to software company (I Presc)

As an example, a knowledge path that occurs when the contribution of a project is a methodology (nomothetic prescriptive) that is applied to an example (idiographic prescriptive). In this way, the knowledge path represents a progression from general, prescriptive knowledge to an instance. To semantically capture the dynamics of the knowledge contributions, the edges in the paths of knowledge

types are labeled. Table 3 illustrates with an example from Ghobadi and Mathiassen [21] who create a model for risk (N Presc) and apply it to a specific software company (I Presc).

Thus, we define the construct *path of knowledge types* as a directed graph, with a sequence of labeled nodes (knowledge type) and edges to represent the dynamic contributions of DSR. A challenge is to identify reasonable labels to assign to obtain some sense of meaning [43]. For the edges, we identified eleven labels from the literature to make explicit the semantics of the links between each node and its successor. These are described in Table 4, where the italics show the abbreviations used.

Table 4: Edge Labels in Paths of Knowledge Types

Label	Description
<i>is applied to</i>	application of abstract artifact or tool, to an example
<i>is tested with or implemented in</i>	relates testable hypotheses or abstract artifacts to tools or prototypes testing the hypotheses or implementing the artifacts
<i>is evaluated by formulating</i>	links abstracts artifacts with testable hypotheses evaluating the artifacts
<i>is completed with</i>	relates an abstract artifact with another abstract artifact that completes it (e.g., first artifact is modeling constraints, second artifact is guideline to help satisfy constraints)
<i>is abstracted into</i>	links idiographic knowledge to nomothetic knowledge abstracted from it, or nomothetic knowledge to more abstract nomothetic knowledge; knowledge goal of source and target nodes is the same
<i>provides practical basis for</i>	links idiographic knowledge to idiographic knowledge derived from it, or idiographic knowledge to nomothetic knowledge that feeds on the idiographic knowledge; types of the source and target nodes differ, otherwise <i>is abstracted into</i> is used
<i>provides constructs for</i>	relates constructs with other knowledge (e.g., a method) defined based on these constructs
<i>provides theoretical basis for</i>	applicable when a nomothetic node uses theoretical (nomothetic) knowledge from its predecessor
<i>provides requirements for</i>	relates requirements to knowledge derived from these requirements
<i>provides principles for</i>	relates design principles to knowledge derived from these principles
<i>precedes</i>	node is not related to its predecessor, but to node further up in path

The knowledge path from nomothetic prescriptive to idiographic prescriptive, N Presc  $\rightarrow$  I Presc (Table 3), can lead to at least two paths of knowledge types as shown in Table 5.

Table 5: Knowledge path options

Knowledge path	Situation where occurs
N Presc $\xrightarrow{\textit{applied}}$ I Presc,	methodology <i>applied</i> to example
N Presc $\xrightarrow{\textit{tested or implemented}}$ I Presc	algorithm <i>implemented</i> in prototype

## 4 Research Steps

### 4.1 Step 1: Define Paths of Knowledge Types

To identify the paths of knowledge types, we performed a *descriptive literature review*, which analyzes trends in a research area based on a representative sample of papers; each paper is a unit of analysis [50]. This type of review involves: selecting sources; searching for, and coding, relevant articles; and performing analyses based on the coding. Identifying a paper as DSR is not always straightforward. To reduce bias in the paper selection, we started by extracting a sample of 32 papers from the intersection of two sets of DSR papers: 1) those from the AIS Senior Scholars' Basket of Eight Journals, identified by Prat et al. [54]; and 2) those identified by Deng et al. [17] in their systematic literature review examining theoretical and empirical design science research.

We coded the papers by representing the contribution of each paper as a *path of knowledge types*, using the labels in Tables 2 and 4. The resulting 32 paths of knowledge types are listed in Appendix A, Table A1. Figure 3 shows the path of knowledge types that appeared most often. An abstract artifact (e.g., method, model) is produced as a nomothetic prescriptive contribution, followed by its implementation in a tool (instantiation), corresponding to idiographic prescriptive knowledge. This material artifact is applied to an example (e.g., real-world data) to evaluate the abstract artifact.

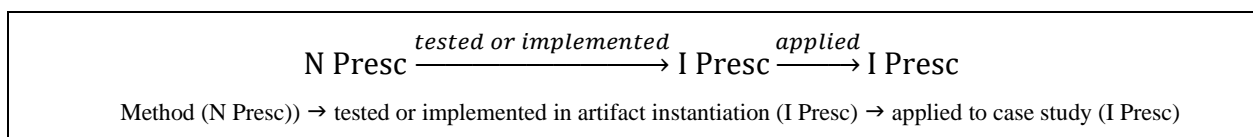


Figure 3. Path of Knowledge Types

Recognizing and following this path of knowledge types suggests that a researcher, who creates a design science method, should recognize the need to implement that method in an artifact and then assess the artifact, preferably, in a real-world situation to address a real-world problem. An example is found in Vandermeer et al. [63] who propose a cost-based database request distribution (C-DBRD) strategy (N Presc), which is implemented (I Presc) and evaluated through application to a field experiment. Xu et al. [68] develop a method for criminal identity matching for fighting drug-related crimes

(N Presc) and implement it as a machine learning method (I Presc), which they then test on an existing data set (I Presc). Roussinov and Chau [57] present a meta-engine approach for supply chain (N Presc), which they implement in a prototype (I Presc) and apply in a simulation (I Presc). Larsen and Bong [38] provide a way to perform natural language processing for large-scale construct identity detection (N Presc), for which they create a tool (I Presc) and evaluate the designs (I Presc). Although these research endeavors vary widely, the path of knowledge types is consistent in indicating the progression a researcher should follow to identify the dynamic contributions of their work.

#### **4.2 Step 2: Evaluate Quality of Paths of Knowledge Types**

We strived to assess the completeness and adequacy of the path of knowledge types construct. The AIS Basket of Eight journals is important for recognizing and disseminating information systems (IS) research, including design science (Figure 1). The basket is commonly used as a representative sample of quality publications when analyzing the IS field [20, 35, 54, 55]. We, therefore, considered the eight journals in the AIS Basket and identified 327 papers from these journals, published between 2004 and 2020. Our first sample of 32 papers (Step 1) represents approximately 10% of papers used. We also computed the distribution of these 327 papers among the eight journals.

- i) We randomly selected a basket of 32 additional papers (another 10%).
- ii) We coded the knowledge contributions of the 32 additional papers by systematically examining the titles of each paper, abstract, and/or full text to identify the paths of knowledge types. The results of this coding are found in Appendix A, Table A2.

The set of knowledge types and the eleven edge labels appeared to be complete and adequate. We judged completeness to mean that the necessary labels existed that could be used to build paths between the nodes. Adequacy was assessed for situations where several link labels between two nodes were possible, and the selection of the label was unambiguous, especially considering the context or projectability. For example, progressing from one idiographic prescriptive node to another, might have labels “*is applied to*,” “*provides practical basis for*,” or “*precedes*.” The link “*is applied to*” relates to

a tool or prototype; “provides *practical basis for*” relates an example to a tool or prototype built or refined based on experience; “*precedes*” is used if the target node is not related to the source node.

### 4.3 Step 3: Classify Paths of Knowledge Types to Derive Research Strategies

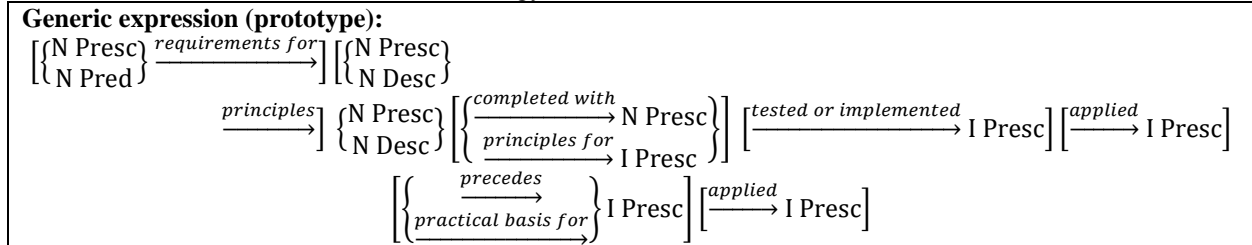
Using the enlarged set of 64 papers, we performed an empirical classification to organize the knowledge contributions into seven categories, we call *strategies* (RQ2). (Classification generally groups entities by similarity [6, 39] resulting in categories.) The variables for assessing the similarities between knowledge contributions are *dimensions*, and the values of the variables, *characteristics* [45]. The entities are the coded papers, grouped into categories based on the similarity of their knowledge contributions. The labels provide the paths with semantics or conceptual (or contextual) knowledge.

The classification process was empirical. The papers were classified into categories of knowledge contributions, based on their paths of knowledge types, and the characteristics of their dimensions (similarities). Several of the dimensions corresponded to those of Iivari [30]. Three researchers performed the classification independently. The resolution of differences involved splitting one category into two, resulting in seven agreed-upon categories, initially called strategies 1-7. Further inspection revealed sets of similar categories, so the numbering was refined as: 1a and 1b, 2a and 2b, 3, and 4a and 4b. Each strategy was carefully labeled to capture its essence, with a generic expression, based on the exemplars in that category. (This balances the “usual prototype approach” (most specific) with the “standard invariant-attribute approach (least specific) [49].) Since the categories that establish the strategies are new, they can be represented using typical or exemplar members [39]; here, the paths of knowledge types. To identify a semantically rich label for each of the general expressions and ensure consistency, a semi-automated procedure was used, as detailed in Appendix B.

Table 6 presents strategy 1a, providing both its generic expression (prototype) and the top four most frequent exemplars found in the paths of knowledge types from which the strategy was derived. Brackets indicate optional; braces indicate alternatives. This strategy emerged the most. It consists of building and instantiating an artifact, which typically involves creating an abstract artifact (nomothetic

prescriptive or nomothetic descriptive), and then applying it to an example (idiographic prescriptive), often implementing it using a tool or prototype.

Table 6. Strategy 1a: Build and Instantiate Artifact



**Paths of knowledge types (exemplars)**

$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc}$
$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc}$
$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$
$\text{N Desc} \xrightarrow{\text{applied}} \text{I Presc}$

Table 7 summarizes the generic expressions for the other six strategies which, similarly, were derived from paths of knowledge types. Strategy 1b is a variation of strategy 1a, where nomothetic definitional *or* nomothetic descriptive knowledge (or both) is defined, and, thus, labeled “build and instantiate artifact, adding to definitional or prescriptive knowledge.” In strategy 2a, *build and generalize from instantiations*, instantiations (idiographic prescriptive) are built and abstracted into design principles. Strategy 2b is a variant of strategy 2a, where the definition of abstract requirements (“meta-requirements”) precedes the definition of instantiations.

In strategy 3, *hypothesize and test propositions*, a researcher defines propositions (nomothetic explanatory and predictive or nomothetic predictive) and tests them. A design artifact (instantiation) is built. This instantiation, typically in the form of a prototype or mockup, is used to test the propositions, often in a controlled experiment (e.g., different groups use different versions of the same prototype). Strategies 4a and 4b frequently build meta-requirements and testable design product hypotheses. Strategy 4a *builds a design theory* without adding to the applied kernel theory or design-relevant explanatory/predictive theory (DREPT [37]). Testable design product hypotheses are always defined, but at varying levels (nomothetic or idiographic) and positions along the paths. Strategy 4b *builds a design*

theory, with knowledge added to the *design-relevant explanatory/predictive theory*. A complete theory may even be defined.

Table 7. Generic Expressions (prototypes) of Strategies 1b to 4b

<p><b>Strategy 1b: Build and instantiate artifact, adding to definitional or descriptive knowledge</b></p> $\left[ \left\{ \begin{array}{l} \text{N Presc} \\ \text{N Desc} \\ \text{N Def} \end{array} \right\} \left\{ \begin{array}{l} \xrightarrow{\text{requirements for}} \\ \xrightarrow{\text{applied}} \\ \xrightarrow{\text{precedes}} \end{array} \right\} \left\{ \begin{array}{l} \text{N Def} \\ \text{N Desc} \end{array} \right\} \left\{ \begin{array}{l} \xrightarrow{\text{constructs for}} \\ \xrightarrow{\text{theoretical basis for}} \end{array} \right\} \left\{ \begin{array}{l} \text{N Presc} \\ \text{N Desc} \\ \text{N Def} \end{array} \right\} \left[ \xrightarrow{\text{completed with}} \text{N Presc} \right] \right]$ $\left[ \xrightarrow{\text{tested or implemented}} \text{I Presc} \right] \left[ \left\{ \begin{array}{l} \xrightarrow{\text{applied}} \\ \xrightarrow{\text{precedes}} \end{array} \right\} \text{I Presc} \right] \left[ \xrightarrow{\text{precedes}} \text{N Presc} \xrightarrow{\text{applied}} \text{I Presc} \right]$
<p><b>Strategy 2a: Build and generalize from instantiations</b></p> $\left[ \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc} \left[ \xrightarrow{\text{principles for}} \text{I Presc} \xrightarrow{\text{applied}} \left\{ \begin{array}{l} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc} \\ \text{N Presc} \end{array} \right\} \right] \right]$
<p><b>Strategy 2b: Build and generalize from theory-grounded instantiations</b></p> $\left[ \left[ \text{N Presc} \xrightarrow{\text{requirements for}} \left\{ \begin{array}{l} \text{N Presc} \\ \text{I Presc} \end{array} \right\} \xrightarrow{\text{applied}} \right] \text{I Presc} \left\{ \begin{array}{l} \xrightarrow{\text{abstracted}} \text{N Presc} \\ \xrightarrow{\text{practical basis for}} \text{N Desc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \end{array} \right\} \right]$
<p><b>Strategy 3: Hypothesize and test propositions</b></p> $\left\{ \begin{array}{l} \text{N Expl\&Pred} \\ \text{N Pred} \end{array} \right\} \xrightarrow{\text{tested or implemented}} \text{I Presc} \left[ \xrightarrow{\text{applied}} \text{I Presc} \right]$
<p><b>Strategy 4a: Build design theory</b></p> $\left[ \left\{ \begin{array}{l} \text{N Presc} \\ \text{N Pred} \end{array} \right\} \xrightarrow{\text{requirements for}} \left[ \text{N Presc} \xrightarrow{\text{tested or implemented}} \left\{ \begin{array}{l} \text{N Presc} \\ \text{N Pred} \\ \text{I Presc} \end{array} \right\} \left\{ \begin{array}{l} \xrightarrow{\text{completed with}} \text{N Pred} \\ \xrightarrow{\text{evaluated by}} \text{N Pred} \\ \xrightarrow{\text{evaluated by}} \text{I Presc} \\ \xrightarrow{\text{precedes}} \text{N Presc} \end{array} \right\} \right] \right]$ $\left\{ \begin{array}{l} \xrightarrow{\text{tested or implemented}} \\ \xrightarrow{\text{precedes}} \end{array} \right\} \text{I Presc} \left[ \xrightarrow{\text{applied}} \text{I Presc} \left[ \xrightarrow{\text{precedes}} \text{I Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \right] \right]$
<p><b>Strategy 4b: Build design theory, adding to design-relevant explanatory/predictive theory</b></p> $\left[ \text{N Def} \xrightarrow{\text{constructs for}} \left\{ \begin{array}{l} \text{N Pred} \\ \text{N Expl\&Pred} \\ \text{I Expl} \\ \text{I Presc} \end{array} \right\} \left[ \left\{ \begin{array}{l} \xrightarrow{\text{theoretical basis for}} \text{N Presc} \\ \xrightarrow{\text{applied}} \text{I Presc} \end{array} \right\} \right] \right]$ $\left[ \left\{ \begin{array}{l} \xrightarrow{\text{requirements for}} \text{N Presc} \left[ \xrightarrow{\text{evaluated by}} \text{N Pred} \right] \\ \xrightarrow{\text{practical basis for}} \text{N Def} \xrightarrow{\text{constructs for}} \text{N Pred} \end{array} \right\} \left[ \xrightarrow{\text{tested or implemented}} \text{I Presc} \right] \xrightarrow{\text{applied}} \text{I Presc} \right]$ $\left[ \xrightarrow{\text{precedes}} \left\{ \begin{array}{l} \text{N Presc} \\ \text{I Presc} \end{array} \right\} \right] \left[ \xrightarrow{\text{applied}} \text{I Presc} \right]$

To further characterize these strategies, we distinguish them by dimensions as adapted from Ivirari [30]. This adaptation was iterative and continued to the definition of the guidelines. Three groups emerged: 1) knowledge production, 2) methods, and 3) resources.



The *Knowledge production* group (closely related to the paths of knowledge types) has three dimensions that characterize a strategy: *major knowledge contributions*, *starting point of the research*, and *dynamic mechanism*. The major knowledge contributions are the nodes that appear frequently in the paths, but have more details than the knowledge types (e.g., method or design principles versus nomothetic prescriptive). The starting point of a research project may be design knowledge, knowledge from the natural or social sciences, or a specific problem, which might not be explicit in the paths. The dynamic interplay between instantiation (or implementation) and generalization (or abstraction) is related to the paths (idiographic vs. nomothetic nodes).

The second group of dimensions is the research and evaluation *methods* used. The first refers to the *genre of DSR* [9]. The second is *research methods in addition to DSR*, which may be quantitative or qualitative research (e.g., action research). The third is *evaluation methods*, characterized by their techniques such as observational and participatory (e.g., case studies) or empirical (e.g., experiment, simulation). The third group, *resources*, is based on the dimensions of *expertise needed*, *involvement of a client*, and *time*.

We compare the seven strategies along these three groups (of three dimensions each). The categories, which are used to establish the strategies are “fully polythetic,” which results from empirical approaches to classification [13]. For each dimension, it is possible to identify a *common characteristic* that is possessed by a large number of entities in the category. Here, the 64 papers are classified into seven categories, with each category becoming a strategy. Although the information needed to characterize the dimensions of group 1 (knowledge production) and group 2 (methods) was readily found in the papers, the dimensions pertaining to resources (group 3) were often implicit. From the 64 papers, we were able to verify that, for each of the six dimensions of groups 1 and 2, there exists a most common characteristic, as shown in Table 8 and Table 9.

Table 8 compares the seven strategies for the knowledge production group (group 1). For each strategy, the table shows the most common characteristics based on the 64 papers. For example, for

strategy 1a, the research generally starts from design knowledge from the knowledge base, making design knowledge the most common characteristic of the “starting point of research” dimension. The dynamic mechanism involves building the artifact and instantiating it, with the artifact and instantiation being the major knowledge contributions. In strategy 1b, research generally starts from design knowledge or knowledge from the natural and social sciences. Strategies 2a and 2b both start from the specific problem of a client and general knowledge. The primary starting point in strategy 2a is a specific problem; in strategy 2b, general knowledge (kernel theory). Similarly for the other strategies.

Table 8. DSR Strategies: Knowledge Production

Strategy	Major knowledge contributions (nodes)	Starting point of research	Dynamic mechanism
Strategy 1a: Build and instantiate artifact	Abstract artifact (model, method). Instantiation (including prototype) as secondary contribution.	Design knowledge.	Build abstract artifact followed by <i>instantiation</i> with prototype (proof of concept, evaluation).
Strategy 1b: Build and instantiate artifact, adding to definitional or descriptive knowledge	Definitional (construct) or descriptive knowledge, often coupled with method. Instantiation as secondary contribution.	Design knowledge or knowledge from natural and social sciences.	Constructs provide a superior level of generality. Abstract artifacts often include methods. <i>Instantiation</i> for demonstration and evaluation.
Strategy 2a: Build and generalize from instantiations	Instantiations. Design principles.	Specific problem of client. Design knowledge or knowledge from natural or social sciences.	Instantiations engrained in practice and used for <i>abstracting</i> design principles.
Strategy 2b: Build and generalize from theory-grounded instantiations	Meta-requirements. Instantiations (including prototype). Design principles.	Knowledge from natural or social sciences (kernel theory). Specific problem of client.	Design principles derived from meta-requirements and <i>abstracted</i> from instantiations.
Strategy 3: Hypothesize and test propositions	Testable propositions. Simple implemented system.	Knowledge from natural and social sciences.	Testable propositions form the abstract knowledge. Primary purpose of <i>implemented</i> system is to test propositions.
Strategy 4a: Build design theory	Meta-requirements. Abstract artifact (model, method). Testable design product hypotheses. Instantiation (including prototype) as secondary contribution.	Knowledge from the natural and social sciences (kernel theory) or design knowledge.	Abstract knowledge comprises meta-requirements, abstract artifact (model, method), and testable design product hypotheses. <i>Instantiation</i> with prototype provides proof of concept and tests design product hypotheses.
Strategy 4b: Build design theory, adding to	Addition to design-relevant explanatory /predictive theory	Knowledge from the natural and	Additions to design-relevant explanatory/predictive theory are

Strategy	Major knowledge contributions (nodes)	Starting point of research	Dynamic mechanism
design-relevant explanatory/predictive theory	(constructs, testable propositions, or causal explanations). Abstract artifact (model, method). Testable design product hypotheses. Instantiation (including prototype) as secondary contribution.	social sciences (kernel theory).	the primary contribution to abstract knowledge, which also comprises the abstract artifact (model, method) and testable design product hypotheses. <i>Instantiation</i> with prototype provides proof of concept and tests design product hypotheses.

Table 9 compares the strategies along the dimensions related to *methods* (the second group of dimensions). For example, the papers in strategy 3 are primarily quantitative, with the prescriptive knowledge exclusively idiographic (instantiations). The genres are not applicable.

Table 9. DSR Strategies: Methods

Strategy	Genre of DSR	Research methods in addition to DSR	Evaluation methods
Strategy 1a: Build and instantiate artifact	Variety of genres with domination of computational genre.	Domination of DSR	Domination of experimental methods.
Strategy 1b: Build and instantiate artifact, adding to definitional or descriptive knowledge	Representation genre.		Domination of observational or participatory methods.
Strategy 2a: Build and generalize from instantiations	Variety of genres.	Action research or other inductive research approach	Refinement of design principles through successive action research cycles.
Strategy 2b: Build and generalize from theory-grounded instantiations			Refinement of design principles through confrontation between theory and practice.
Strategy 3: Hypothesize and test propositions	Not applicable.	Quantitative research	Controlled experiment using the implemented system to test the propositions.
Strategy 4a: Build design theory	Computational genre.		Domination of experimental methods.
Strategy 4b: Build design theory, adding to design-relevant explanatory/predictive theory	Variety of genres.		Variety of evaluation methods.

Finally, the strategies are compared based on their resource requirements. The characterization of strategies is based on Iivari [30], as well as the authors' knowledge and experience. Strategy 1a (and, to a lesser extent, strategy 1b) corresponds to Iivari's strategy 1 and has the same resource

requirements. Strategies 2a and 2b correspond to Iivari's strategy 2. The main differences in resource requirements are as follows.

For *expertise needed*, the composition of the research teams is often disciplinary for strategies 1a, 1b, 3, 4a and 4b, and multi-disciplinary for strategies 2a and 2b. In strategies 4a and 4b, depending on the kernel theory, multi-disciplinary teams may be required. In strategies 1a, 2a, 2b, 3, 4a and 4b, resources are often needed to develop a prototype. In strategy 1b, often a prototype is not required. In strategy 3, the primary role of an implemented system is to test the hypothesized propositions, so the development may be minimal.

The *involvement of a client* is generally required for strategies 2a and 2b, but not for strategy 3, and optional in the other strategies. Strategy 1b often resorts to observational and participatory methods, involving the participation of practitioners in evaluation. In strategies 2a and 2b, projects usually occur over an extended period of time (e.g., action research). Strategy 3 does not necessarily require an extended period. In strategies 4a and 4b, the development of the design theory adds up to the time needed to build and evaluate the abstract artifact.

Thus, considering the dimensions provides a reasonable way to assess how to use the strategies.

#### **4.4 Step 4: Evaluate Classification of Seven Strategies**

One way to verify the quality of a categorization is by assessing its fully polythetic property [13]. Grouping the knowledge contributions as knowledge production and methods shows that the seven strategies are *fully polythetic* in the sense that, for each strategy and the dimensions that comprised it, the characteristics of the strategy are possessed by most papers in that strategy. The 64 papers displayed the fully polythetic property for the nine dimensions, based on available information.

To evaluate the robustness of the seven categories, we randomly selected, and coded, an additional set of 64 papers from the remaining papers. Appendix A, Table A3 details their paths of knowledge types and strategies. Two authors coded the 64 papers; disagreements were studied and resolved. The results showed, first, that the eleven labels were sufficient to code all the articles. Second, we double-

checked alternative paths to verify the consistency of the labels. Third, we were successfully able to classify the 64 papers into the seven strategies. Two researchers classified the papers independently, empirically assessing the completeness of the strategies. The robustness of the classification was evident from the fact that the researchers classified 92% of the papers identically.

To further validate the seven strategies, we coded an extra sample of papers from *Decision Support Systems (DSS)*. The time span was the same as used previously (2004 to 2020). Due to the large number of papers, we focused on the most cited ones, based on citation scores from Google Scholar and Web of Science. The result was a sample of 74 papers. From these, we identified the DSR papers (using the same criteria as previously applied). This resulted in 19 papers (basket 4). The independent coding of these papers (Appendix A, Table A4) by two researchers revealed no new strategy. Further, we found only one new path, N Presc  $\xrightarrow{\text{requirements for}}$  N Presc, consistent with strategy 1a and compatible with its generic expression. This additional validation supports the robustness of the strategies.

Table 10 summarizes the frequency of papers for each strategy.

Table 10. Distribution of Papers Reviewed by Strategy

Strategy	STEP 1	STEP 2	STEP 4		Total	Frequency
	Basket 1	Basket 2	Basket 3	Basket 4		
1a	10	20	42	17	89	61%
1b	10	6	10	0	26	18%
2a	1	1	6	0	8	5%
2b	1	1	2	0	4	3%
3	2	1	3	2	8	5%
4a	6	0	1	0	7	5%
4b	2	3	0	0	5	3%
Total	32	32	64	19	147	100%

Overall, these efforts resulted in the construct of the path of knowledge types with labeled edges (*RQ1*) and the identification of seven strategies that represent the progression of a DSR project (*RQ2*). Guidelines for initiating and developing knowledge contributions (*RQ3*) can now be developed.

#### 4.5 Step 5: Guidelines Based on Paths of Knowledge Types and Strategies

We derived guidelines for initiating and conducting DSR based on the derivation of the strategies and paths and the identification of the paths of the 128 papers in Tables A1, A2 and A3 (Appendix A). This is in response to RQ3, which focuses on identifying strategies to guide researchers so their knowledge contributions can be developed. Guidelines G1 and G2 address initiating knowledge contributions; G3 and G4 pertain to developing a knowledge contribution. It is important to first select a strategy (G1 and G2) because each strategy produces diverse knowledge types, requires different resources, and resorts to different methods (the three groups of dimensions). Evaluation and publication standards differ. For developing knowledge contributions (G3 and G4), a researcher can: 1) remain with the same strategy (G3); or 2) switch strategies (G4).

##### 1. Initiating a Knowledge Contribution: Choosing the Initial Strategy

When initiating a DSR project, a strategy depends on the three dimensions of: type of knowledge produced, methods used, and resources required.

*Guideline G1. Initiate a DSR project.*

*At the beginning of a DSR project, examine the context and select the strategy based on the project's characteristics.*

The context includes the problem or opportunity, and the available resources. Problems and opportunities are the problem of a client, a research question, a research gap, a research challenge, or a research opportunity [44]. Strategies are characterized by the knowledge produced (Table 8), methods used (Table 9), and resource requirements. The prototype of a strategy (Table 6, Table 7) also characterizes the knowledge produced, which, in turn, dictates the choice of methods and resources requirements. The wording of a research question might suggest what knowledge should be produced [44]. For example, “how” often indicates prescriptive knowledge [22]. Even though it might be natural to select a strategy by starting from the characteristics of knowledge production, all characteristics of the strategies are possible entry points; for example, starting from the available resources.

## **2. Initiating a Knowledge Contribution: Building the Initial Path**

Researchers need to build the initial path of knowledge types. They should examine the strategies and their exemplars to build a rich knowledge contribution. A rich path captures the possible interactions and complements between the various categories of knowledge goals and knowledge scope. Each node in the path shows the knowledge produced. Guideline G2 summarizes the choice of this path.

*Guideline G2. Build initial knowledge.*

*Starting from a strategy, examine the prototype and exemplars to identify potential paths of knowledge types.*

Researchers should strive to produce rich paths that capture the dynamic and pluralistic nature of DSR, taking advantage of the possible interactions between different knowledge goals and knowledge scope. A path might be enriched by introducing new nodes or diversifying the knowledge types of the nodes.

When choosing between candidate exemplars of a strategy, the researcher may consider the frequency of the exemplars. An exemplar is a path of knowledge types. Frequency is the number of papers in which the path appears. A frequent path, as the one in Figure 3, may be considered a safe choice. However, infrequent paths may be more interesting as they have higher entropy [60].

## **3. Developing a Knowledge Contribution: Extending the Path within a Strategy**

Researchers who have already built an initial path of knowledge types can use the paths of existing strategies to further exploit their research. A strategy to do so is determined similarly to guideline G1; the context comprises the path built so far. The paths may contain nodes not suggested by, or present in, the paths of the strategy. The following guideline develops a knowledge contribution:

*Guideline G3. Progress ongoing research by matching path and exemplars.*

*Identify the strategy to which this research pertains, and match the path traveled to the exemplars of this strategy to identify the next possible nodes.*

## **4. Developing a Knowledge Contribution: Switching Strategies**

Researchers who have already built an initial knowledge contribution and wish to pursue a different or more innovative approach, may switch from one strategy to another.

*Guideline G4. Progress ongoing research with new path.*

*If matching the path traveled with the prototype and exemplars of a given strategy no longer leads to alternatives, switch to a different strategy. For disruptive strategies, attempt to conduct research by drawing an edge between strategies.*

When switching strategies, the choice of the target strategy depends on its characteristics, with the prototype and exemplars of the target strategy suggesting continuations of paths.

To switch strategies, use the end node of a strategy as the starting node of the next one. In strategy 1a, researchers might have developed a generic tool (idiographic prescriptive) they can use as the starting node for strategy 2a, applying it in a company. However, switching from strategy i to strategy j, when the end node of strategy i may be the starting node of strategy j, is not very innovative. A more disruptive approach explores possible links between strategies, where the source and target strategies may be related by intermediary links. A “genuinely new invention” is difficult [8]; disruptive research may define new paths of knowledge types, by exploring the strategies and possible links between them.

Figure 4 shows a partial graph to chaining strategies. Grey links represent cases where a final node among the paths of the source strategy is of the same type as a starting node of the target strategy. As mentioned, strategies starting with the same number (e.g., 2a and 2b) are similar, as reflected by the names of the strategies. Therefore, switching from one strategy to a strategy starting with a different number (e.g., 1b to 4a) may be considered more disruptive than switching to a strategy starting with the same number (e.g., 2a to 2b). Figure 4 shows only the grey links between strategies starting with different numbers. Some innovative links are in bold; others are possible. Links to strategies 4a and 4b are especially relevant because design theories are often considered as the most accomplished form of design knowledge. For example, propositions tested in strategy 3 may feed the development of a design theory in strategy 4a, providing the basis for defining a meta-artifact. These propositions play the role of meta-requirements. Artifact evaluation in strategies 1a or 1b may provide material for defining a DREPT in strategy 4b.



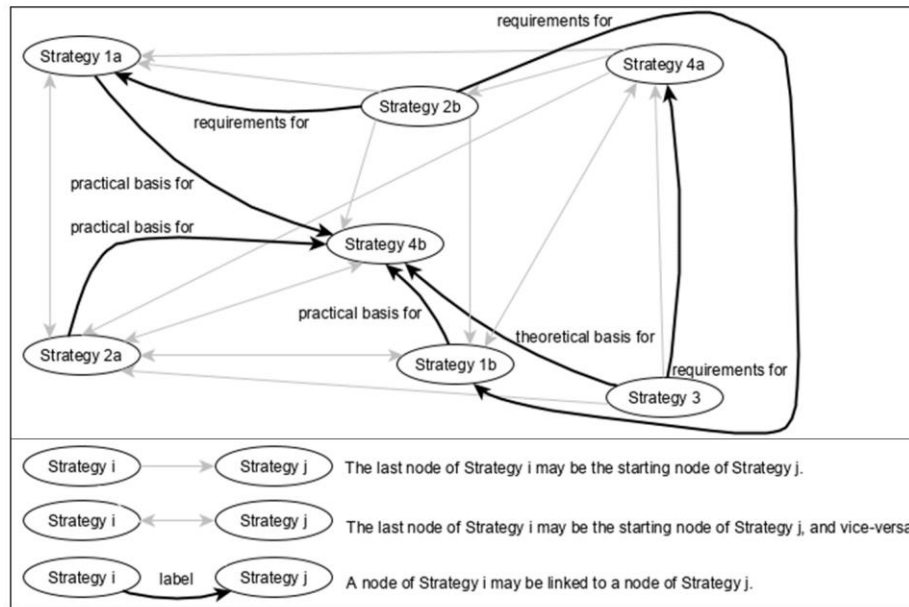


Figure 4. Potential chaining strategies

A chaining strategy can support a researcher in considering an appropriate next strategy. It helps identify when a project might have progressed to completion or whether it might be possible to achieve further knowledge contributions. A researcher could also benefit from the visual representation which shows there are multiple ways in which a pluralistic DSR project can progress.

#### 4.6 Step 6: Evaluating the Utility of the Guidelines

The utility of the guidelines is demonstrated by showing the paths and strategies for two applications.

##### Application of Guideline G1

Assume the research question is: *“How can we develop a methodology to help managers choose anonymization solutions for sensitive data?”* The literature review identifies algorithms and tools, but not methodologies for selecting among them. Data anonymization is a crucial part of securing cyberspace (National Academy of Engineering<sup>3</sup>) in a world where networks are ubiquitous and cyberattacks, commonplace. To address the research question, researchers want to start from a concrete application, since the topic is relevant to many companies. Therefore, strategy 2a is appropriate since instantiations are a major knowledge contribution in this strategy and engrained in practice (Table 8).

<sup>3</sup> <http://www.engineeringchallenges.org/challenges/cyberspace.aspx>

However, suppose no client is available, which precludes using action research (strategies 2a and 2b). The wording of the research question (“*How...*”) suggests a focus on producing nomothetic prescriptive knowledge. Strategy 3, which does not produce such knowledge and whose research method is quantitative, is excluded. The researchers strive to produce a design theory (strategy 4a or 4b). However, the literature review did not reveal any kernel theory or design theory from which to start (characteristic “starting point of the research”). Strategies 1a and 1b remain applicable.

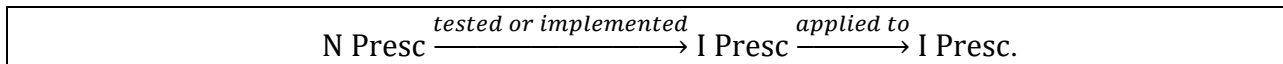
The effectiveness of data anonymization depends on knowing a potential attacker, who would seek to re-identify the anonymous information. Before defining the methodology for the data owners making anonymization decisions, the researchers must represent the adversary model, as descriptive knowledge. For “major knowledge contributions,” the researchers choose strategy 1b since descriptive knowledge is typically produced in this strategy. In the latter, a method is often produced, so the researchers need to define a methodology (an ordered sequence of phases and steps) as a special case of a method. Table 9 shows that strategy 1b often uses observational and participatory evaluation methods, suggesting the need to resort to practitioners (data owners) to evaluate the methodology.

### **Application of Guideline G2**

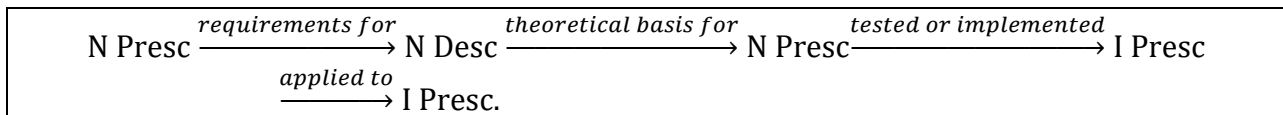
Strategy 1b has been chosen for the secure cyberspace project that develops a methodology for choosing anonymization solutions. From the generic path expression for strategy 1b, the researchers initiate the path as  $N \text{ Presc} \xrightarrow{\text{requirements for}} N \text{ Desc}$ .  $N \text{ Desc}$  is the adversary model, whose requirements are derived from the literature review. The path is then continued as:  $N \text{ Desc} \xrightarrow{\text{theoretical basis for}} N \text{ Presc}$ . This is similar to Arnott [2], where a classification of cognitive biases (nomothetic descriptive) provides a theoretical basis for defining a methodology. Continuing strategy 1b, the researchers consider completing the methodology with other nomothetic prescriptive knowledge ( $N \text{ Presc} \xrightarrow{\text{completed with}} N \text{ Presc}$ ). They examine the corresponding exemplar [51] where a prescriptive model for

good classification structures is completed with rules for constructing and evaluating the structures. There is no nomothetic prescriptive knowledge to complete the methodology.

Further along the generic path of strategy 1b, the researchers could evaluate the methodology by applying it to an example (N Presc  $\xrightarrow{\text{applied to}}$  I Presc). However, an option to generate a richer path is to build a prototype and then apply it to an example:



Building a tool to support the methodology for choosing anonymization solutions would be a significant contribution. Finally, the researchers consider the end of the generic path expression ( $\xrightarrow{\text{precedes}}$  N Presc  $\xrightarrow{\text{applied to}}$  I Presc), which is not relevant (no new nomothetic prescriptive knowledge to produce). The complete path is built by drawing on the generic path expression of strategy 1b. Its exemplar is:

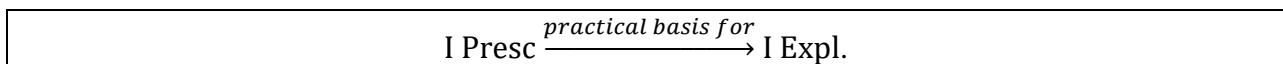


Each node in this sequence is an artifact produced: a set of requirements, an adversary model, a methodology, a tool, and an application to an example, respectively.

### Application of Guideline G3

Assume an initial knowledge contribution, with researchers wishing to pursue further research. Koch et al. [36], for example, use action research to design and implement a mobile health application to teach marginalized people in India about hypertension. There are three emerging lessons, which are insights on the interaction aspect of project management control in social innovation collaborations.

Assume the path built so far is:



The first node is the application of a project management approach. The second node represents the lessons from this research for this specific case (explanation of the mechanisms of project

management control). We assume the researchers wish to develop this contribution, extending the path. They should first identify the strategy to which this path pertains. The latter does not match any path in the seven strategies, as can be seen in the generic path expressions. However, the starting node of the path and the research method (action research) suggest strategy 2a is relevant. The node I Presc (the first node in the path for this research), is matched with the second node I Presc in the generic path of strategy 2a. (The first part of this generic path expression, I Presc  $\xrightarrow{\text{applied to}}$ , is optional and represents the situation where a tool is first built and applied). From the second node I Presc in the generic path expression, the researchers may continue to N Presc (abstraction of design principles from the application of the project management approach). The initial path is thus extended as:

$$\text{I Presc} \xrightarrow{\text{practical basis for}} \text{I Expl} \xrightarrow{\text{precedes}} \text{N Presc}.$$

The design principles are not derived directly from the explanations, but, rather, abstracted from the concrete experience – idiographic prescriptive – in the first node. After deriving the design principles, the generic path of strategy 2a suggests that the path may be continued, with:

$$\xrightarrow{\text{principles for}} \text{I Presc} \xrightarrow{\text{applied to}} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc}.$$

By examining the exemplars where this section of the path appears, the researchers recognize a second action research cycle being performed, which refines the design principles by applying them to another example (I Presc  $\xrightarrow{\text{applied to}}$  is optional and represents situations when a tool is first built). In the present situation, the goal is to apply the design principles to design and implement an application in a country other than India or to another domain. The complete path is extended as:

$$\text{I Presc} \xrightarrow{\text{practical basis for}} \text{I Expl} \xrightarrow{\text{precedes}} \text{N Presc} \xrightarrow{\text{principles for}} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc}.$$

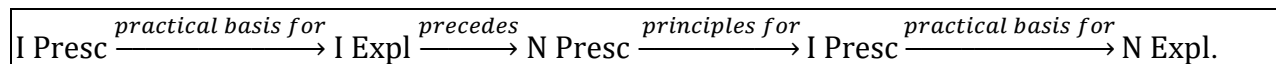
Strategy 2a is then saturated: the generic path for this strategy has no new path extensions.

### Application of Guideline G4

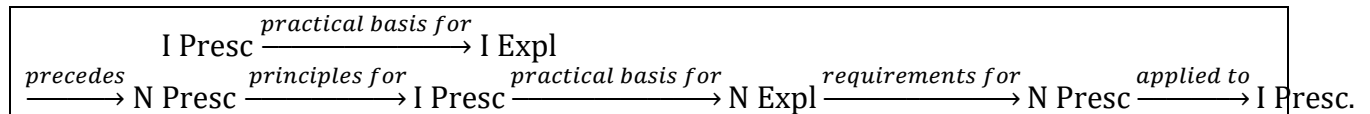
Furthering the above, if researchers want to develop their knowledge contribution further, they can consider switching strategies to capitalize on the experience accumulated over the two action research cycles. They start from the second I Presc node in the path built so far:



They wish to develop a design theory (strategy 4a or 4b). The experience accumulated suggests building a DREPT, as part of the design theory, thus switching to strategy 4b. The DREPT will be an explanatory theory about IS project management control in social innovation collaborations. Among the paths of strategy 4b, the researchers seek explanatory knowledge. They find a node I Expl in the path of Chen et al. [16], and move to this node. Contrary to Chen et al. [16], the explanatory knowledge developed in this case is not idiographic, but nomothetic (explanatory theory regarding IS project management control in social innovation collaborations, based on the two action research cycles). The experience provides a practical basis for defining this knowledge, hence the path:



Switching from strategy 2a to strategy 4b is performed through the last link of the path. The last node (N Expl) is matched with the node (I Expl) in the path of Chen et al. [16]. The researchers continue along the path of this paper: the explanatory theory about IS project management control in social innovation collaborations provides requirements for the meta-artifact (a methodology), which is evaluated with an example. The complete path is:



Hence, the construct of the path of knowledge types associated with research strategies led to the four guidelines that can be used for initiating and developing knowledge contributions.

## 5 Discussion

This research analyzed DSR knowledge contributions as a DSR project passes through different knowledge moments. Recognizing that it is challenging it is to both create an artifact and contribute to design knowledge, we introduced *paths of knowledge types* to represent the dynamic and pluralistic knowledge contributions. We coded each knowledge contribution of representative design science research papers as a path of knowledge types. The paths were classified into seven strategies for knowledge creation based on: the knowledge contributions, starting point of a project, dynamic mechanism, genre of DSR, method, and approach to evaluation. From these strategies, we derived guidelines for conducting and progressing DSR.

### 5.1 Contributions

This research recognizes that the production of knowledge contributions in design science research is dynamic or pluralistic, which has been often overlooked in the literature. Researchers can represent the knowledge contribution of a project as a path and match that path to a strategy to continue their work. Guidelines G1 and G2 help researchers initiating a DSR project to select a research strategy and a path of knowledge types to follow. Guidelines G3 and G4 help researchers progress from a knowledge contribution. Guideline G4, which establishes bridges between strategies, facilitates knowledge accumulation by building on one's previous research or that of others. Knowledge accumulation is crucial, but generally lacking in design science research [58], except for some recent initiatives [66]. Knowledge accumulation requires integration of behavioral and design perspectives [46] and conceptual and empirical perspectives [58].

The paths of knowledge types specifically capture dynamic and pluralistic contributions as characterized by knowledge goals and knowledge scope (conceptual/nomothetic versus empirical/ideographic). The paths also provide the transparency and preciseness needed for knowledge accumulation [58]. Following the nodes in the paths of knowledge types refines the communication work of Gregor

and Hevner [23] because it suggests a natural order for presenting contributions. A main contribution is the *path of knowledge types* artifact, which we use to represent prior research and derive strategies and guidelines. Our work (this paper) pertains to strategy 1b as shown in Figure 5.

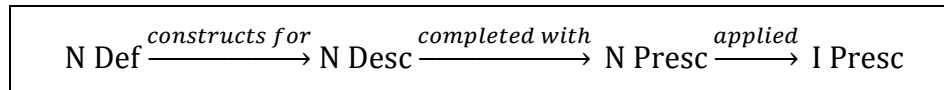


Figure 5. Path of Knowledge Types for this Paper

## 5.2 Comparison to Prior Work

Tables 11 and 12 compare our work to other, influential work that characterizes or classifies knowledge contributions in design science research. The tables show how prior work can be expressed in terms of our research and indicate (final column) how our work extends that of prior efforts.

Table 11. Comparison to Prior Work on Knowledge Contributions in Design Science Research

Prior Study	Main elements of prior study	Mapping of our work to prior study	Complements of our work
March and Smith [41]; Hevner et al. [29]	DSR contributions: build and evaluate artifacts; typology of artifacts	Constructs → nomothetic definitional; models → nomothetic prescriptive or descriptive; methods → nomothetic prescriptive; instantiations → idiographic prescriptive. Build and evaluate artifacts → strategies 1a and 1b.	Strategies 2a to 4b
Gregor and Jones [24]	DSR contributions: building design theories; components of design theories.	Build design theories → strategies 4a and 4b.	Strategies 1a to 3. Paths of knowledge types: capture dynamics.
Gregor and Hevner [23]	3 levels of contribution types; knowledge contribution framework; communication schema.	Level 1 → idiographic prescriptive. Level 2 → nomothetic definitional, nomothetic descriptive, or nomothetic prescriptive. Level 3 → strategies 4a and 4b.	Distinguishes knowledge types (level 1) and strategies (level 3). Paths of knowledge types: refine DSR communication schema: present results by following nodes in paths.
Drechsler and Hevner [18]	Six modes of utilizing or contributing knowledge: labeled links from project design knowledge to human knowledge or vice-versa.	Links in modes of utilizing or contributing knowledge → labeled edges in paths of knowledge types for transitions.	Beyond links: defines construct of path of knowledge types, based on links, classifies existing studies based on paths.
Rothe, Wessel and Barquet [56]	Accumulation along goals and scope of design knowledge by 3 knowledge creation mechanisms (injection, folding, enhancement); 3 patterns of knowledge creation.	Both studies characterize knowledge by its scope and goals [9]. Accumulation along scope and goals of design knowledge through the 3 mechanisms → path of knowledge types.	Nodes in paths of knowledge types refine characterization of knowledge goals. Edge labels refine the 3 mechanisms. Strategies and guidelines for developing knowledge contributions.

Prior Study	Main elements of prior study	Mapping of our work to prior study	Complements of our work
Vom Brocke et al. [66]	Design knowledge map, representing contributions in three-dimensional space: (projectability, fitness, confidence); four archetypes of knowledge evolution and accumulation across projects; guidelines.	Movements in the space → paths of knowledge types. Projectability related to distinction between nomothetic and idiographic.	Design knowledge maps are coarse-grained, illustrating knowledge accumulation through series of projects. Paths of knowledge types are granular, detailing the knowledge contribution within a project (and possibly across projects).

Table 12. Comparison to Prior Work on Classification of Design Science Research

Prior Study	Main elements of prior study	Mapping of our work to prior study	Complements of our work
Iivari [30]	2 strategies conceptually defined; 16 dimensions to characterize strategies. Focus: technology artifacts.	16 dimensions (with focus on design) → 9 dimensions (design and science). Strategy 1 → refined into strategies 1a and 1b. Strategy 2 → refined into strategies 2a and 2b.	Strategies 3, 4a, and 4b new. Strategies (categories) empirically defined. Guidelines for developing knowledge contributions, based on strategies.
Peffer et al. [52]	Five genres. Objective: standards and values for genres. Method for defining genres: interpretive review.	IS design theories → strategies 4a and 4b. DSR methodology and design-oriented IS research → strategies 1a and 1b. Explanatory design theory → strategy 3. Action design research → strategies 2a and 2b.	Objective to help researchers initiate and develop knowledge contributions. Method for identifying strategies: descriptive literature review combined with classification of knowledge contributions represented as paths of knowledge types.

### 5.3 Limitations and Future Research

The structure of a *path of knowledge types* provides a logical order of knowledge production. However, there is no guarantee that this structure captures all progressions of knowledge generation. Even though the AIS Basket of Eight is often used for content analysis, it may not reflect all the diversity and richness of DSR endeavors. This motivated us to further validate our approach with an extra 19 publications (basket 4 from DSS). All 147 papers contribute idiographic prescriptive and nomothetic knowledge of various kinds. Papers classified in strategy 3, however, might be considered at the frontier with behavioral research. Since the paths of knowledge types were identified from a sample of DSR papers, additional papers may reveal paths not identified so far.



Although our work is on DSR, the construct of a path of knowledge types should be generalizable to any knowledge contribution in IS research. Its application could result in new strategies and associations, in a truly meta-paradigmatic manner, and include epistemological issues associated with standards [26]. For DSR, it might even be possible to accumulate knowledge contributions in a repository of successful paths. Information systems development deals with complexity [33]. The next generation of DSR will, undoubtedly, deal with increasing complexity [14]. Acknowledging the different contributions of a project as it progresses should help deal with such complexity.

## 6 Conclusion

Design science research has developed many useful artifacts and knowledge contributions. To represent these contributions, we propose a *path of knowledge types* construct to capture the dynamic, and pluralistic, nature of a design science research project. This construct was applied to a representative set of design science research papers and the results classified into seven strategies, which formed the basis for a set of guidelines to assist researchers in initiating and progressing a design science research project. The guidelines were illustrated, and comparisons made to prior work on knowledge contributions and classifications. This research also addresses the need for representation, classification, and methodological guidance. Future research will apply the strategies to other design science research projects, and information systems in general, to further assess their effectiveness.

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## APPENDIX A

### CODING OF ARTICLES

Figure A1 shows the form used to codify the papers as paths of knowledge types.

	A	B	C
1	Paper ID	MISQ34	
2	Nodes and links forming the path of knowledge types (Each column, starting from column B, is a node or a link. Each node is characterized by a knowledge type).		
3	Describe the artifact(s) or knowledge for each node (examples: taxonomy of mobile applications, algorithm for data scrambling, structural equation model explaining and predicting the success of a particular type of IS).	<ul style="list-style-type: none"> <li>Nomothetic Definitional</li> <li>Nomothetic Descriptive</li> <li>Nomothetic Prescriptive</li> <li>Nomothetic Explanatory</li> <li>Nomothetic Predictive</li> <li>Nomothetic Explanatory and Predictive</li> <li>Idiographic Descriptive</li> <li>Idiographic Prescriptive</li> <li>Idiographic Explanatory</li> <li>Idiographic Predictive</li> <li>Idiographic Explanatory and Predictive</li> </ul>	
	Notes (Enter in column B any comments about the coding of this paper).		

	A	B	C
1	Paper ID	MISQ34	
2	Nodes and links forming the path of knowledge types (Each column, starting from column B, is a node or a link. Each node is characterized by a knowledge type).	Nomothetic Prescriptive	
3	Describe the artifact(s) or knowledge for each node (examples: taxonomy of mobile applications, algorithm for data scrambling, structural equation model explaining and predicting the success of a particular type of IS).	A new design research method: ADR (Action Design Research).	<ul style="list-style-type: none"> <li>is abstracted into</li> <li>is applied to</li> <li>is completed with</li> <li>is evaluated by formulating</li> <li>is tested with or implemented in</li> <li>precedes</li> <li>provides constructs for</li> <li>provides practical basis for</li> <li>provides principles for</li> <li>provides requirements for</li> <li>provides theoretical basis for</li> </ul>
	Notes (Enter in column B any comments about the coding of this paper).		

**Figure A2. Coding Form**

The tables below show the resulting paths for all 147 papers: the 32 papers from the first basket in Table A1, the 32 additional papers from the second basket in Table A2, the 64 additional papers from the third basket in Table A3, and the 19 additional papers from the fourth basket in Table A4.

**Table A1. Sample of Articles from the First Basket**

Article	Path of knowledge types	Strategy
“Cybergate: A design framework and system for text analysis of computer-mediated communication” by Abbasi and Chen [2]	$N \text{ Presc} \xrightarrow{\text{requirements for}} N \text{ Presc} \xrightarrow{\text{evaluated by}}$ $N \text{ Pred} \xrightarrow{\text{precedes}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc} \xrightarrow{\text{precedes}}$ $I \text{ Pred} \xrightarrow{\text{tested or implemented}} I \text{ Presc}$	4a
“Detecting fake websites: The contribution of statistical learning theory” by Abbasi et al. [4]	$N \text{ Presc} \xrightarrow{\text{requirements for}} N \text{ Pred} \xrightarrow{\text{precedes}} N \text{ Presc}$ $\xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	4a
“Metafraud: A meta-learning framework for detecting financial fraud” by Abbasi et al. [1]	$N \text{ Pred} \xrightarrow{\text{requirements for}} N \text{ Presc}$ $\xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	4a

Article	Path of knowledge types	Strategy
"The effects of tree-view based presentation adaptation on mobile web browsing" by Adipat et al. [6]	$\begin{array}{c} \text{N Pred} \xrightarrow{\text{tested or implemented}} \text{I Presc} \\ \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	3
"Making sense of technology trends in the information technology landscape: A design science approach" by Adomavicius et al. [7]	$\begin{array}{c} \text{N Def} \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{precedes}} \text{N Presc} \\ \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	1b
"GIST: A model for design and management of content and interactivity of customer-centric web sites" by Albert et al. [10]	$\text{N Def} \xrightarrow{\text{constructs for}} \text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1b
"A theory-driven design framework for social recommender systems" by Arazy et al. [11]	$\begin{array}{c} \text{N Expl\&Pred} \xrightarrow{\text{theoretical basis for}} \text{N Presc} \\ \text{requirements for} \xrightarrow{\text{evaluated by}} \text{N Presc} \xrightarrow{\text{evaluated by}} \text{N Pred} \\ \text{tested or implemented} \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	4b
"Cognitive biases and decision support systems development: A design science approach" by Arnott [12]	$\text{N Desc} \xrightarrow{\text{theoretical basis for}} \text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1b
"Integrating biosignals into information systems: A neuroIS tool for improving emotion regulation" by Astor et al. [13]	$\begin{array}{c} \text{N Presc} \xrightarrow{\text{requirements for}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \\ \xrightarrow{\text{abstracted}} \text{N Presc} \end{array}$	2b
"Guidelines for designing visual ontologies to support knowledge identification" by Bera et al. [16]	$\begin{array}{c} \text{N Presc} \xrightarrow{\text{evaluated by}} \text{N Pred} \xrightarrow{\text{tested or implemented}} \\ \text{I Presc} \end{array}$	4a
"Design principles for virtual worlds" by Chaturvedi et al. [28]	$\text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc}$	2a
"Data model development for fire related extreme events: An activity theory approach" by Chen et al. [29]	$\begin{array}{c} \text{N Def} \xrightarrow{\text{constructs for}} \text{I Expl} \xrightarrow{\text{requirements for}} \text{N Presc} \\ \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{precedes}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	4b
"Implementing service-oriented architecture in organizations" by Choi et al. [30]	$\text{N Expl\&Pred} \xrightarrow{\text{tested or implemented}} \text{I Presc}$	3
"Modeling spatial and temporal set-based constraints during conceptual database design" by Currim and Ram [33]	$\text{N Desc} \xrightarrow{\text{theoretical basis for}} \text{N Def} \xrightarrow{\text{applied}} \text{I Presc}$	1b
"A semantic approach to secure collaborative inter-organizational ebusiness processes (SSCIOBP)" by D'Aubeterre et al. [34]	$\begin{array}{c} \text{N Presc} \xrightarrow{\text{requirements for}} \text{N Def} \xrightarrow{\text{constructs for}} \\ \text{N Desc} \xrightarrow{\text{precedes}} \text{I Presc} \end{array}$	1b
"A theory of tailorable technology design" by Germonprez et al. [45]	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a

Article	Path of knowledge types	Strategy
"Service-oriented methodology for systems development" by Keith et al. [63]	$N \text{ Presc} \xrightarrow{\text{requirements for}} N \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
"A design approach for collaboration processes: A multimethod design science study in collaboration engineering" by Kolfshoten and de Vreede [66]	$N \text{ Presc} \xrightarrow{\text{requirements for}} N \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
"Process grammar as a tool for business process design" by Lee et al. [75]	$N \text{ Def} \xrightarrow{\text{constructs for}} N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1b
"Explaining data-driven document classifications" by Martens and Provost [84]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
"A multilevel model for measuring fit between a firm's competitive strategies and information systems capabilities" by McLaren et al. [86]	$N \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
"Using enterprise architecture analysis and interview data to estimate service response time" by Närman et al. [94]	$N \text{ Presc} \xrightarrow{\text{requirements for}} N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
"A systematic methodology for privacy impact assessments: A design science approach" by Oetzel and Spiekermann [96]	$N \text{ Def} \xrightarrow{\text{constructs for}} N \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1b
"Using cognitive principles to guide classification in information systems modeling" by Parsons and Wand [101]	$N \text{ Def} \xrightarrow{\text{constructs for}} N \text{ Presc} \xrightarrow{\text{completed with}} N \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1b
"The design theory nexus" by Pries-Heje and Baskerville [104]	$N \text{ Def} \xrightarrow{\text{constructs for}} N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1b
"Knowing what a user likes: A design science approach to interfaces that automatically adapt to culture" by Reinecke and Bernstein [107]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{evaluated by}} I \text{ Presc}$ $I \text{ Pred} \xrightarrow{\text{tested or implemented}} I \text{ Presc}$	4a
"Combining information seeking services into a meta supply chain of facts" by Roussinov and Chau [110]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
"Designing enterprise integration solutions: effectively" by Umapathy et al. [123]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
"A cost-based database request distribution technique for online e-commerce applications" by VanderMeer et al. [124]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a

Article	Path of knowledge types	Strategy
“Design of emerging digital services: A taxonomy” by Williams et al. [135]	N Def $\xrightarrow{\text{applied}}$ I Presc	1b
“Complex problem solving: Identity matching based on social contextual information” by Xu et al. [138]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
“Alternate strategies for a win-win seeking agent in agent-human negotiations” by Yang et al. [141]	N Presc $\xrightarrow{\text{requirements for}}$ N Presc $\xrightarrow{\text{evaluated by}}$ N Pred $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	4a

Table A2. Sample of 32 Additional Papers (Basket 2)

Article	Path of knowledge types	Strategy
“Don’t mention it? Analyzing user-generated content signals for early adverse event warnings” by Abbasi et al. [3]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc	1a
“Modeling interferences in information systems design for cyberphysical systems: Insights from a smart grid application” by Brandt et al. [18]	N Presc $\xrightarrow{\text{applied}}$ I Presc $\xrightarrow{\text{abstracted}}$ I Presc	2b
“Supporting agile organizations with a decision guidance query language” by Brodsky et al. [21]	N Def $\xrightarrow{\text{completed with}}$ N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1b
“Thinking about measures and measurement in positivist research: A proposal for refocusing on fundamentals” by Burton-Jones and Lee [22]	N Presc $\xrightarrow{\text{completed with}}$ N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
“Affordances, experimentation and actualization of FinTech: A blockchain implementation study” by Du et al. [41]	I Presc $\xrightarrow{\text{abstracted}}$ N Presc	2a
“A generic cloud migration process model” by Fahmideh et al. [42]	N Presc $\xrightarrow{\text{principles for}}$ N Desc $\xrightarrow{\text{applied}}$ I Presc	1b
“Top persuader prediction for social networks” by Fang and Jen-Hwa Hu [43]	N Presc $\xrightarrow{\text{requirements for}}$ N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
“Targeted twitter sentiment analysis for brands using supervised feature engineering and the dynamic architecture	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a



Article	Path of knowledge types	Strategy
for artificial neural networks” by Ghiassi et al. [46]		
“Risks to effective knowledge sharing in agile software teams: A model for assessing and mitigating risks” by Ghobadi and Mathiassen [47]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
“On the fintech revolution: Interpreting the forces of innovation, disruption, and transformation in financial services” by Gomber et al. [48]	N Def $\xrightarrow{\text{applied}}$ I Presc	1b
“Understanding information systems integration deficiencies in mergers and acquisitions: A configurational perspective” by Henningsson and Kettinger [55]	N Desc $\xrightarrow{\text{principles for}}$ N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
“Graph-based cluster analysis to identify similar questions: A design science approach” by John et al. [59]	N Presc $\xrightarrow{\text{completed with}}$ N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1b
“Control patterns in a health-care network” by Kartseva et al. [61]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
“Towards analysing the rationale of information security non-compliance: Devising a value-based compliance analysis method” by Kolkowska et al. [67]	N Presc $\xrightarrow{\text{requirements for}}$ N Presc $\xrightarrow{\text{principles for}}$ N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
“Extending digital infrastructures: A typology of growth tactics” by Koutsikouri et al. [68]	N Desc $\xrightarrow{\text{applied}}$ I Presc	1a
“Process models representing knowledge for action: A revised quality framework” by Krogstie et al. [70]	N Desc $\xrightarrow{\text{applied}}$ I Presc	1a
“The use of cognitive maps and case-based reasoning for b2b negotiation” by Lee and Kwon [76]	N Desc $\xrightarrow{\text{completed with}}$ N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc	1b
“Design theory for market surveillance systems” by Li et al. [79]	N Expl&Pred $\xrightarrow{\text{theoretical basis for}}$ N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	4b
“Healthcare predictive analytics for risk profiling in chronic care: A bayesian multitask learning approach” by Lin et al. [80]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a

Article	Path of knowledge types	Strategy
"Characteristics of IT artifacts: A systems thinking-based framework for delineating and theorizing IT artifacts" by Matook and Brown [85]	N Desc $\xrightarrow{\text{applied}}$ I Presc	1a
"Privacy and big data: scalable approaches to sanitize large transactional databases for sharing" by Menon and Sarkar [88]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Designing a requirement mining system" by Meth et al. [89]	N Presc $\xrightarrow{\text{principles for}}$ N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc	1a
"Are business users social? A design experiment exploring information sharing in enterprise social systems" by Mettler and Winter [90]	N Expl&Pred $\xrightarrow{\text{tested or implemented}}$ I Presc	3
"Web footprints of firms: Using online isomorphism for competitor identification" by Pant and Sheng [98]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc	1a
"Supporting the design of data integration requirements during the development of data warehouses: A communication theory-based approach" by Rosenkranz et al. [108]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"A structured approach for designing collaboration experiences for virtual worlds" by Schmeil et al. [114]	N Desc $\xrightarrow{\text{applied}}$ I Presc	1a
"Conceptualizing routing decisions in business processes: Theoretical analysis and empirical testing" by Soffer et al. [120]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Design and evaluation of auto-id enabled shopping assistance artifacts in customers' mobile phones: Two retail store laboratory experiments" by Venkatesh et al. [125]	I Presc $\xrightarrow{\text{applied}}$ I Presc $\xrightarrow{\text{practical basis for}}$ N Def $\xrightarrow{\text{constructs for}}$ N Pred $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc $\xrightarrow{\text{precedes}}$ N Presc	4b
"The 'darth' side of technology use: an inductively derived typology of cyber-deviance" by Venkatraman et al. [126]	N Def $\xrightarrow{\text{applied}}$ I Presc	1b
"Cost-effective quality assurance in crowd labeling" by Wang et al. [130]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc	1a

Article	Path of knowledge types	Strategy
“The association between the disclosure and the realization of information security risk factors” by Wang et al. [132]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc}$	1a
“Measuring customer agility from online reviews using big data text analytics” by Zhou et al. [147]	$N \text{ Def} \xrightarrow{\text{constructs for}} N \text{ Pred} \xrightarrow{\text{tested or implemented}}$ $I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	4b

Table A3. Sample of 64 Additional Papers (Basket 3)

Article	Path of knowledge types	Strategy
“Text analytics to support sense-making in social media: A language-action perspective” by Abbasi et al. [5]	$N \text{ Presc} \xrightarrow{\text{requirements for}} N \text{ Presc}$ $\xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
“Toward comprehensive real-time bidder support in iterative combinatorial auctions” by Adomavicius and Gupta [8]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc}$	1a
“REQUEST: A query language for customizing recommendations” by Adomavicius et al. [9]	$N \text{ Def} \xrightarrow{\text{completed with}} N \text{ Def} \xrightarrow{\text{constructs for}} I \text{ Presc}$	1b
“Recommending remedial learning materials to students by filling their knowledge gaps” by Bauman and Tuzhilin [14]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
“The transformative value of cloud computing: A decoupling, platformization, and recombination theoretical framework” by Benlian et al. [15]	$N \text{ Def} \xrightarrow{\text{applied}} I \text{ Presc}$	1b
“Evaluating team collaboration quality: The development and field application of a collaboration maturity model” by Boughzala and de Vreede [17]	$N \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
“Comprehensible predictive models for business processes” by Breuker et al. [19]	$N \text{ Presc} \xrightarrow{\text{tested or implemented}} I \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a
“Facilitator-in-a-box: Process support applications to help practitioners realize the potential of collaboration technology” by Briggs et al. [20]	$N \text{ Presc} \xrightarrow{\text{requirements for}} N \text{ Presc} \xrightarrow{\text{applied}} I \text{ Presc}$	1a

Article	Path of knowledge types	Strategy
"Guidelines for empirical evaluations of conceptual modeling grammars" by Burton-Jones et al. [24]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"How can we develop contextualized theories of effective use? A demonstration in the context of community-care electronic health records" by Burton-Jones and Volkoff [23]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc	1a
"Designing a core IT artefact for Knowledge Management Systems using participatory action research in a government and a non-government organisation" by Butler et al. [25]	I Presc $\xrightarrow{\text{practical basis for}}$ N Desc $\xrightarrow{\text{tested or implemented}}$ I Presc	2b
"Cost-sensitive learning via priority sampling to improve the return on marketing and CRM investment" by Cui et al. [32]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Theory-informed design and evaluation of an advanced search and knowledge mapping system in nanotechnology" by Dang et al. [35]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Leveraging financial social media data for corporate fraud detection" by Dong et al. [37]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"An agent-based collaborative approach to graphing causal maps for situation formulation" by Druckenmiller and Acar [39]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Developing and maintaining clients' trust through institutional mechanisms in online service markets for digital entrepreneurs: A process model" by Du and Mao [40]	I Presc $\xrightarrow{\text{abstracted}}$ N Presc	2a
"Company information privacy orientation: A conceptual framework" by Greenaway et al. [49]	NDesc $\xrightarrow{\text{applied}}$ I Presc	1a
"Creating strategic business value from big data analytics: A research framework" by Grover et al. [50]	NDef $\xrightarrow{\text{applied}}$ I Presc	1b
"The persuasive power of algorithmic and crowdsourced advice" by Gunaratne et al. [51]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a

Article	Path of knowledge types	Strategy
"Extracting representative information on intra-organizational blogging platforms" by Guo et al. [53]	$\begin{array}{c} \text{N Presc} \xrightarrow{\text{requirements for}} \text{N Presc} \\ \text{tested or implemented} \xrightarrow{\hspace{1.5cm}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	1a
"Combining geographical and social influences with deep learning for personalized point-of-interest recommendation" by Guo et al. [52]	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
"Design theory for dynamic complexity in information infrastructures: The case of building internet" by Hanseth and Lyytinen [54]	$\text{N Presc} \xrightarrow{\text{principles for}} \text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
"A unified model of requirements elicitation" by Hickey and Davis [56]	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
"Sleight of hand: Identifying concealed information by monitoring mouse-cursor movements" by Jenkins et al. [58]	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
"The emergence of online community leadership" by Johnson et al. [60]	$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc}$	1a
"Disentangling digital platform competition: The case of UK mobile payment platforms" by Kazan et al. [62]	$\text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc}$	2a
"Advanced customer analytics: Strategic value through integration of relationship-oriented big data" by Kitchens et al. [64]	$\begin{array}{c} \text{N Presc} \xrightarrow{\text{completed with}} \text{N Presc} \\ \text{tested or implemented} \xrightarrow{\hspace{1.5cm}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	1b
"Co-creation in virtual worlds: The design of the user experience" by Kohler et al. [65]	$\begin{array}{c} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc} \\ \text{principles for} \xrightarrow{\hspace{1.5cm}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc} \end{array}$	2a
"A framework for theory development in design science research: Multiple perspectives" by Kuechler and Vaishnavi [71]	$\text{N Def} \xrightarrow{\text{applied}} \text{I Presc}$	1b
"Detecting review manipulation on online platforms with hierarchical supervised learning" by Kumar et al. [72]	$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
"A tool for addressing construct identity in literature reviews and meta-analyses" by Larsen and Bong [73]	$\begin{array}{c} \text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \\ \text{practical basis for} \xrightarrow{\hspace{1.5cm}} \text{I Presc} \end{array}$	1a

Article	Path of knowledge types	Strategy
"Matching mobile applications for cross-promotion" by Lee et al. [74]	$\begin{array}{l} \text{N Expl\&Pred} \\ \xrightarrow{\text{tested or implemented}} \text{N Presc} \xrightarrow{\text{tested or implemented}} \\ \text{I Presc} \xrightarrow{\text{precedes}} \text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \end{array}$	4a
"Digression and value concatenation to enable privacy-preserving regression" by Li and Sarkar [78]	$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
"Design principles for competence management systems: A synthesis of an action research study" by Lindgren et al. [81]	$\begin{array}{l} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc} \xrightarrow{\text{principles for}} \text{I Presc} \\ \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc} \end{array}$	2a
"Finding useful solutions in online knowledge communities: A theory-driven design and multilevel analysis" by Liu et al. [82]	$\begin{array}{l} \text{N Presc} \xrightarrow{\text{requirements for}} \text{N Presc} \xrightarrow{\text{completed with}} \\ \text{N Pred} \xrightarrow{\text{tested or implemented}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	4a
"Digital product innovation within four classes of innovation networks" by Lyytinen et al. [83]	$\text{N Def} \xrightarrow{\text{constructs for}} \text{N Desc}$	1b
"Research Note—Generating shareable statistical databases for business value: Multiple imputation with multimodal perturbation" by Melville and McQuaid [87]	$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc}$	1a
"From requirements to implementations: A model-driven approach for web development" by Montero et al. [91]	$\text{N Def} \xrightarrow{\text{constructs for}} \text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1b
"Pluralist theory building: A methodology for generalizing from data to theory" by Müller et al. [93]	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc} \xrightarrow{\text{abstracted}} \text{N Presc}$	2b
"Conceptualizing business-to-thing interactions – A sociomaterial perspective on the Internet of Things" by Oberländer et al. [95]	$\text{N Desc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
"Usable, in-use, and useful research: A 3U framework for demonstrating practice impact" by Pan and Pee [97]	$\text{N Def} \xrightarrow{\text{completed with}} \text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1b
"Status locality on the web: Implications for building focused collections" by Pant and Srinivasan [99]	$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc}$	1a

Article	Path of knowledge types	Strategy
“Generating effective recommendations using viewing-time weighted preferences for attributes” by Parsons and Ralph [100]	$\begin{array}{c} \text{N Expl\&Pred} \xrightarrow{\text{tested or implemented}} \text{IPresc} \\ \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	3
“Feedback at scale: Designing for accurate and timely practical digital skills evaluation” by Piccoli et al. [102]	$\begin{array}{c} \text{N Presc} \xrightarrow{\text{requirements for}} \text{N Presc} \xrightarrow{\text{principles for}} \\ \text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	4a
“Taking stock of organisations’ protection of privacy: Categorising and assessing threats to personally identifiable information in the USA” by Posey et al. [103]	$\text{NDesc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
“Finding similar mobile consumers with a privacy-friendly geosocial design” by Provost et al. [105]	$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc}$	1a
“Brute-force sentence pattern extortion from harmful messages for cyberbullying detection” by Ptaszynski et al. [106]	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
“Managing evolutionary method engineering by method rationale” by Rossi et al. [109]	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
“Research Note—The Halo effect in multicomponent ratings and its implications for recommender systems: The case of Yahoo! movies” by Sahoo et al. [111]	$\text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
“A hidden Markov model for collaborative filtering” by Sahoo et al. [112]	$\text{N Presc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
“Capturing the complexity of gamification elements: A holistic approach for analysing existing and deriving novel gamification designs” by Schöbel et al. [115]	$\text{NDesc} \xrightarrow{\text{applied}} \text{I Presc}$	1a
“Toward a better measure of business proximity: Topic modeling for industry intelligence” by Shi et al. [117]	$\begin{array}{c} \text{N Presc} \xrightarrow{\text{tested or implemented}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \\ \xrightarrow{\text{precedes}} \text{I Presc} \xrightarrow{\text{applied}} \text{I Presc} \end{array}$	1a

Article	Path of knowledge types	Strategy
"A data-mining approach to identification of risk factors in safety management systems" by Shi et al. [116]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"IT-based reminders for medication adherence: Systematic review, taxonomy, framework and research directions" by Singh and Varshney [118]	N Desc $\xrightarrow{\text{completed}}$ N Def	1b
"Goal-driven multi-process analysis" by Soffer and Wand [119]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Autonomous scientifically controlled screening systems for detecting information purposely concealed by individuals" by Twyman et al. [122]	N Presc $\xrightarrow{\text{principles for}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Special issue editorial - Accumulation and evolution of design knowledge in design science research: A journey through time and space" by vom Brocke et al. [127]	N Desc $\xrightarrow{\text{completed with}}$ N Desc N Desc $\xrightarrow{\text{completed with}}$ I Presc $\xrightarrow{\text{completed with}}$ I Presc	1b
"Platform ontologies for the model-driven architecture" by Wagelaar and Van Der Straeten [128]	N Def $\xrightarrow{\text{constructs for}}$ N Desc $\xrightarrow{\text{completed with}}$ N Presc N Desc $\xrightarrow{\text{tested or implemented}}$ I Presc	1b
"Copycats vs. original mobile apps: A machine learning copycat-detection method and empirical analysis" by Wang et al. [131]	N Expl&Pred $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	3
"Preserving user preferences in automated document-category management: An evolution-based approach" by Wei et al. [134]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Artificial immune systems for the detection of credit card fraud: An architecture, prototype and preliminary results" by Wong et al. [136]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"‘Computing’ requirements for open source software: A distributed cognitive approach" by Xuan et al. [140]	I Presc $\xrightarrow{\text{abstracted}}$ N Presc	2a
"Aligning with new digital strategy: A dynamic capabilities approach" by Yeow et al. [142]	I Presc $\xrightarrow{\text{abstracted}}$ N Presc	2a
"Large-scale network analysis for online social brand advertising" by Zhang et al. [146]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a



Table A4. Sample of 19 Additional Papers (Basket 4)

Article	Path of knowledge types	Strategy
"Improving supply chain performance management: A systematic approach to analyzing iterative KPI accomplishment" by Cai et al. [26]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Exploring determinants of voting for the 'helpfulness' of online user reviews: A text mining approach" by Cao et al. [27]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Modeling wine preferences by data mining from physicochemical properties" by Cortez et al. [31]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Leveraging the capabilities of service-oriented decision support systems: Putting analytics and big data in cloud" by Demirkan and Delen [36]	N Presc $\xrightarrow{\text{requirements for}}$ N Presc	1a
"Integrating experts' weights generated dynamically into the consensus reaching process and its applications in managing non-cooperative behaviors" by Dong et al. [38]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Predicting crime using Twitter and kernel density estimation" by Gerber [44]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Manipulation of online reviews: An analysis of ratings, readability, and sentiments" by Hu et al. [57]	N Expl&Pred $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	3
"Deep learning for affective computing: Text-based emotion recognition in decision support" by Kratzwald et al. [69]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Using text mining and sentiment analysis for online forums hotspot detection and forecast" by Li and Wu [77]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"A data-driven approach to predict the success of bank telemarketing" by Moro et al. [92]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Predicting the performance of online consumer reviews: A sentiment mining approach to big data analytics" by Salehan and Kim [113]	N Expl&Pred $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	3
"Sales forecasting using extreme learning machine with applications in fashion retailing" by Sun et al. [121]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a

Article	Path of knowledge types	Strategy
"A multi-objective optimization for green supply chain network design" by Wang et al. [129]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Leveraging deep learning with LDA-based text analytics to detect automobile insurance fraud" by Wang and Xu [133]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Disaster early warning and damage assessment analysis using social media data and geo-location information" by Wu and Cui [137]	N Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Consensus model for multi-criteria large-group emergency decision making considering non-cooperative behaviors and minority opinions" by Xu et al. [139]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"Combining belief functions based on distance of evidence" by Yong et al. [143]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"The impact of social and conventional media on firm equity value: A sentiment analysis approach" by Yu et al. [144]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a
"The determinants of crowdfunding success: A semantic text analytics approach" by Yuan et al. [145]	N Presc $\xrightarrow{\text{tested or implemented}}$ I Presc $\xrightarrow{\text{applied}}$ I Presc	1a

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## APPENDIX B

### GENERATING GENERIC PATH EXPRESSIONS

The semi-automated procedure generating the path expression for a strategy is shown below. A group of the research team applied the procedure to generate the expressions for the seven strategies, and the other group verified the results, leading to fine-tuning of the procedure.

The procedure groups all identical paths inside a strategy, computing for each path the length (number of nodes) and the number of instances (number of papers) (line 3). The paths are then sorted by descending order of path length and descending order of number of instances (line 4). The idea is to map the paths of a strategy by starting with the most complex and common paths. The mapping (lines 6 to 12) matches nodes and edges of paths. It requires expertise human expertise to match paths of knowledge types based on the semantics, and sometimes requires getting back to the coded papers. Based on this mapping, the generic path expression is generated for the path, considering optional and alternative expressions (lines 13 to 39). This part of the procedure is automated. It only requires deciding on the sort order when the frequency of two expressions, as judged by the number of path instances, is the same.

1. **Input:** a strategy  $S$  (i.e., a category of paths of knowledge types)
2. **Output:** the generic path expression  $G$  of  $S$
3. Group all identical paths inside  $S$ , computing for each path the number of instances and the length of the path // The length of a path is the total number of nodes in that path.
4. Sort the resulting list of paths by descending order of path length and descending order of number of instances. Call this list  $L$ .
5. Initialize  $A = \text{array}(\text{length}(L), 2 \times \text{length}(L(1)) - 1)$  // Array  $A$  is initialized with one row for each path in  $L$ , and one column for each element (edge or node) in the first path of  $L$ .
6. **For** each element  $e_i$  in  $L(1)$  //  $e_i$  is either a node or an edge
7.      $A(1,i) = e_i$
8. **For**  $i = 2$  to  $\text{length}(L)$
9.     **For** each element  $e_j$  in  $L(i)$
10.         Choose the column in  $A$  where  $e_j$  should be placed // The researcher decides what column is the best match for  $e_j$ . This column should be after the column where  $e_{j-1}$  was placed. It may need to be inserted as a new column of  $A$ .
11.         Call  $k$  the index of that column
12.          $A(i,k) = e_j$
13. Initialize  $G = ""$ ,  $i = 1$
14. **While**  $i \leq$  the number of columns in  $A$
15.     Initialize  $j = 1$
16.     **While** the values in column  $j+1$  of  $A$  are on the same rows as the values in column  $j$  of  $A$
17.          $j = j+1$
18.     Call  $k$  the number of non-empty rows in the subarray  $A(1:\text{length}(L), i:j)$
19.     **If**  $k < L$
20.         Add "[" to the expression  $G$

```

21. Call  $l$  the number of distinct non-empty rows in the subarray  $A(1:\text{length}(L),i:j)$ 
22. Initialize  $B = \text{array}(l,j-i+1)$ 
23. Fill array  $B$  with the subarray  $A(1:\text{length}(L),i:j)$ , with duplicates and empty rows removed
24. Initialize  $q = 1$ 
25. While  $q \leq$  the number of columns in  $B$ 
26.     Initialize  $r = 1$ 
27.     While column  $r+1$  of  $B$  has the same number of distinct non-empty rows as column  $r$  of  $B$ 
28.         Call  $s$  the number of distinct non-empty rows in the subarray  $B(1:l,q:r)$ 
29.         Fill array  $C$  with the subarray  $B(1:l,q:r)$ , with duplicates removed
30.         If  $s > 1$ 
31.             Sort the rows of  $C$  by decreasing number of path instances // In case of equality in the number of path instances, the choice of the ordering is left to the researcher.
32.             Add "{" to the expression  $G$ 
33.             Add the array  $C$  to the expression  $G$ 
34.             If  $s > 1$ 
35.                 Add "}" to the expression  $G$ 
36.         If  $k < L$ 
37.             Add "]" to the expression  $G$ 
38.          $i = j+1$ 
39. Return  $G$ 

```

**Figure B1. Procedure for Generating Generic Path Expressions**