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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.

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 [1]. 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 [2]. 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

Abbreviations: DSR, Design Science Research.

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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 [3]: 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

Fig. 1 shows the progression of design science research through a set of eras, noting influential works as found in journals and prominent conference publications.[1]

Simon's [4] *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 [5]. Nunamaker et al. [6] presented information systems development as a research methodology. Walls et al. [7] made an initial attempt to formalize DSR, followed by March and Smith [8] and Hevner et al. [9], who note the importance of design science in decision support. Gregor and Hevner [10] proposed initial guidelines. Diverse artifacts appear in socio-technical systems, for which design science is needed [11]. Arnott and Pervan [12,13] argue that design science research provides a way to improve decision support. Other notable efforts include Sein et al. [14] on action design research. Attempts to establish DSR as a paradigm included a special issue in *MIS Quarterly* [15] and a method publication [16]. The eras progressed to include the development of many DSR artifacts [17] and topics such as: evaluation [18]; frameworks [19]; design principles [20]; context and projectability [21]; creativity [22]; innovation [23]; design logic [24]; resources [25] and theories [31,57,26].

Efforts to organize the vast literature on design science research analyze the research conducted throughout these eras [1,27,28,29,30]. 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 [2]. The purpose of design is prescriptive; science is descriptive, explanatory, or predictive. The second, *knowledge scope*, contrasts abstract artifacts with material artifacts or instantiations [31]. 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 [2]. The third dichotomy originates from two views of knowledge contributions: artifacts and design theories.

Hevner et al. [9] identify contributions as abstract artifacts (constructs, models, methods) or instantiations [8]. Eierman et al. [32] relate Simon's work [4] to a set of broad decision support constructs. Walls et al. [7] state that DSR should produce *design theories*, with kernel theories, meta-requirements, meta-design, and testable hypotheses. Gregor and Hevner [10] distinguish prescriptive (Λ) and descriptive knowledge (Ω). 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 [2]. Akoka et al. [33] 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 [34] 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 [35]. Rothe et al. [29] 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 [36] 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 [37] identify six modes of design theorizing, which capture some dynamics of knowledge production. Vom Brocke et al. [3] 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. [16]), methodologies for artifact building (e.g., action research [14]), evaluation [17,18], resources [25], and categories [25,35]. Iivari [25] proposes two categories, which 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 [17] or research gaps [38].

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, characterizing 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

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

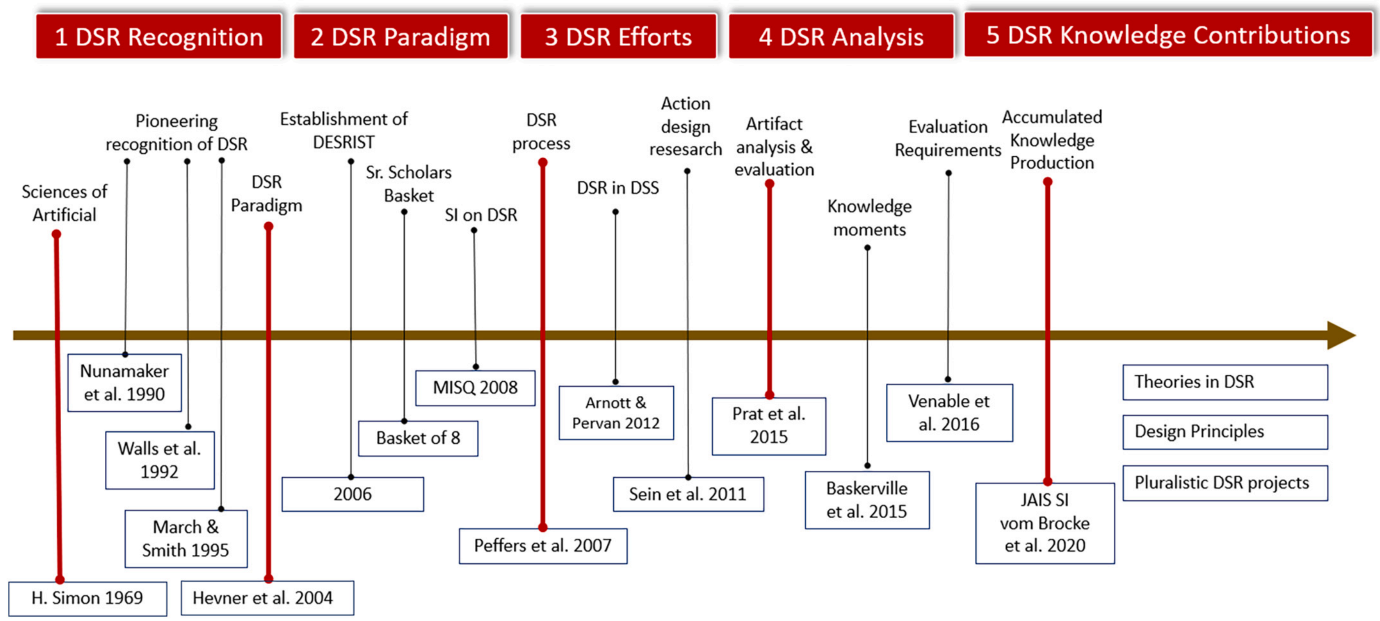

Fig. 1. Progression of design science research eras.

knowledge paths [33] 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 [39]. The main terms are first described in Table 1.

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 question *RQ1* (represent knowledge contributions), we enrich the knowledge paths of Akoka et al. [33] to propose a *path of knowledge types* construct that captures the dynamic nature of knowledge contributions.[2] For *RQ2* (identify and characterize 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. Fig. 2 provides an overview of the steps followed in this research.

Table 1
Description of terms.

Knowledge type: DSR Knowledge as characterized by its scope and goal [33].
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) [2].
Knowledge goal: Primary goal of knowledge produced; "what the [knowledge] is for" [40]; may be for analyzing, explaining, predicting, prescribing.
Definitional knowledge: concepts required to express knowledge in other categories (descriptive, explanatory, predictive, explanatory and predictive, prescriptive) [35].
Descriptive knowledge: "what is" [40,35].
Explanatory knowledge: "how" and "why" things happened [40].
Predictive knowledge: what will happen if preconditions hold, with no causal explanations [40].
Explanatory and predictive knowledge (together): what will happen if preconditions hold and provide causal explanations [40].
Prescriptive knowledge: how something should be done [40].
Knowledge moment: episode of knowledge production, characterized by scope and goal [2], viewed in multiple ways: scientific pluralism [41].
Knowledge path: a chronological ordered set of knowledge types [33].
Path of knowledge types (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.

3.2. 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 [2]. 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) [2,39] and by knowledge goals, which can be *definitional, descriptive, explanatory, predictive*, or *prescriptive* [35]. (Although there is some debate over whether true nomothetic knowledge contributions exist, this distinction appears in the literature [2,42]). 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.

The dynamic part is captured through successive knowledge moments, which can be represented by a *knowledge path* [33]. Table 3

[2] 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.britannica.com/science/construct. Accessed 27 August 2022. We thank an anonymous reviewer for encouraging us to consider this term.

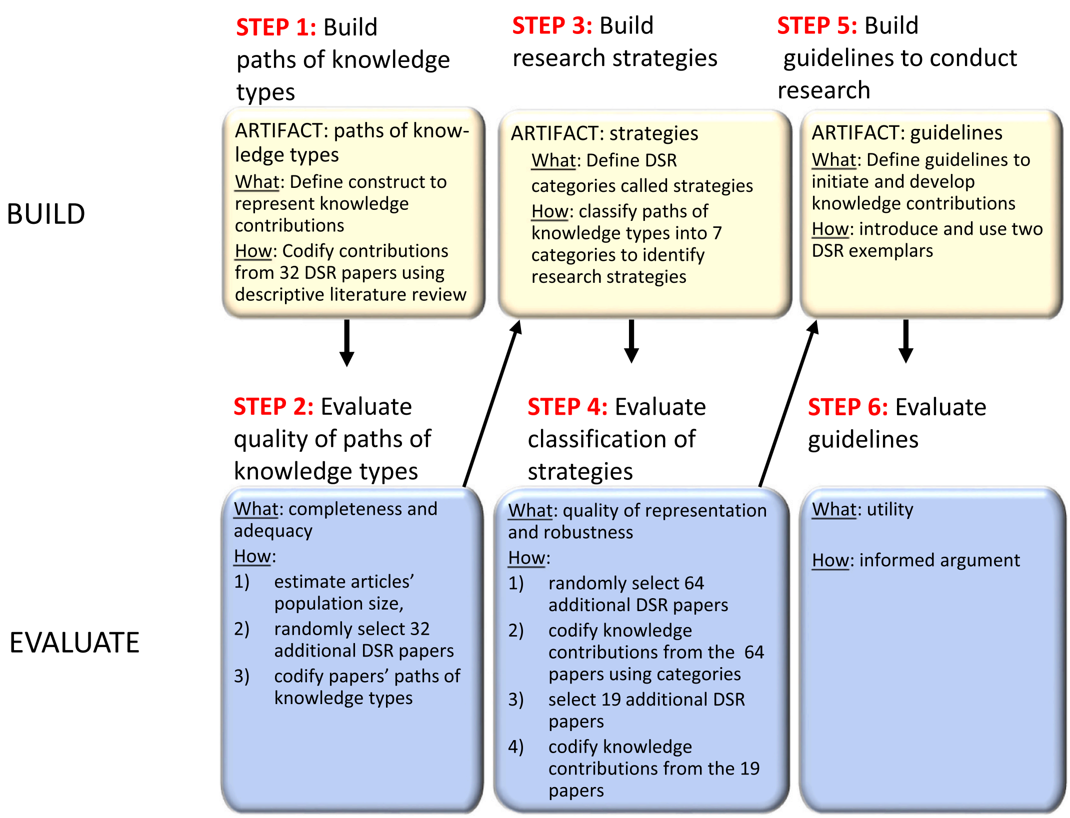

Fig. 2. Research approach (based on build-and-evaluate [9]).

Table 2
Knowledge types in design science research.

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

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 Mathiassen [43]
Nomothetic prescriptive knowledge	Model to 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	N Presc $\xrightarrow{applied}$ I Presc Risk model (N Presc) applied to software company (I Presc)

shows how to represent and interpret a knowledge path from general (nomothetic) knowledge that is prescriptive to specific (idiographic) prescriptive knowledge.

As an example, a knowledge path 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 [43] 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 types) and edges to represent the dynamic contributions of DSR. A challenge is to identify reasonable labels to assign to obtain some sense of meaning [44]. 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.

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

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 [45].

Table 4
Edge labels in paths of knowledge types.

Label	Description
is *applied* to	application of abstract artifact or tool, to an example
is *tested* with *or implemented* in	relates testable hypotheses or abstract artifacts to tools or prototypes testing the hypotheses or implementing the artifacts
is *evaluated by* formulating	links abstracts artifacts with testable hypotheses evaluating the artifacts
is *completed with*	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)
is *abstracted* into	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
provides *practical basis for*	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 *is abstracted into* is used
provides *constructs for*	relates constructs with other knowledge (e.g., a method) defined based on these constructs
provides *theoretical basis for*	applicable when a nomothetic node uses theoretical (nomothetic) knowledge from its predecessor
provides *requirements for*	relates requirements to knowledge derived from these requirements
provides *principles for*	relates design principles to knowledge derived from these principles
precedes	node is not related to its predecessor, but to node further up in path

Table 5
Knowledge path options.

Knowledge path	Situation where occurs
$\text{N Presc} \xrightarrow{applied} \text{I Presc}$	methodology *applied* to example
$\text{N Presc} \xrightarrow{tested\ or\ implemented} \text{I Presc}$	algorithm *implemented* in prototype

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. [17]; and 2) those identified by Deng et al. [46] 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 the online supplementary material (Appendix A), Table A1. Fig. 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.

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. [47] 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. [48] 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 [49] 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 [50] 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 (Fig. 1). The basket is commonly used as a representative sample of quality publications when analyzing the IS field [1,51,17,52]. 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 the online supplementary material (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 directly 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

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

Method (N Presc)) → tested or implemented in artifact instantiation (I Presc) → applied to case study (I Presc)

Fig. 3. Path of knowledge types.

Table 6
Strategy 1a: build and instantiate artifact.

Generic expression (prototype):
$\left[\left\{\begin{matrix}\text{N Presc}\\ \text{N Pred}\end{matrix}\right\}\xrightarrow{\textit{requirements for}}\right]\left[\left\{\begin{matrix}\text{N Presc}\\ \text{N Desc}\end{matrix}\right\}\xrightarrow{\textit{principles}}\right]\left\{\begin{matrix}\text{N Presc}\\ \text{N Desc}\end{matrix}\right\}\left[\left\{\begin{matrix}\xrightarrow{\textit{completed with}}\text{N Presc}\\ \xrightarrow{\textit{principles for}}\text{I Presc}\end{matrix}\right\}\right]\left[\xrightarrow{\textit{tested or implemented}}\text{I Presc}\right]\left[\xrightarrow{\textit{applied}}\text{I Presc}\right]\left[\left\{\begin{matrix}\xrightarrow{\textit{precedes}}\\ \xrightarrow{\textit{practical basis for}}\end{matrix}\right\}\text{I Presc}\right]\left[\xrightarrow{\textit{applied}}\text{I Presc}\right]$

Paths of knowledge types (exemplars)

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

categories, which we call *strategies* (RQ2). Classification generally groups entities by similarity [53,54], resulting in categories. The variables for assessing the similarities between knowledge contributions are *dimensions*, and the values of the variables, *characteristics* [55]. 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 [25]. 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) [56].) Since the categories that establish the strategies are new, they can be represented using typical or exemplar members [54]; here, the paths of knowledge types. To identify a semantically rich label for each of the generic expressions and ensure consistency, a semi-automated procedure was used, as detailed in Appendix A, of the online supplementary material, Section 2.

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

Table 7
Generic expressions (prototypes) of strategies 1b to 4b.

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

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 *instantiation* 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. *Instantiation* 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 *abstracting* 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 *abstracted* 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 *implemented* 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. *Instantiation* with prototype provides proof of concept and tests design product hypotheses.
Strategy 4b: Build design theory, adding to design-relevant explanatory/predictive theory	Addition to 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.	Knowledge from the natural and social sciences (kernel theory).	Additions to design-relevant explanatory/predictive theory are the primary contribution to abstract knowledge, which also comprises the abstract artifact (model, method) and testable design product hypotheses. *Instantiation* with prototype provides proof of concept and tests design product hypotheses.

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 7 summarizes the generic expressions for the other six strategies which, similarly, were derived from paths of knowledge types. Strategy 1b is a variant 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 descriptive 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 [57]). 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.

To further characterize these strategies, we distinguish them by dimensions as adapted from Iivari [25]. 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* [2]. 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 [58]. 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 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.

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.

Finally, the strategies are compared based on their resource requirements. The characterization of strategies is based on Iivari [25], 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 [58]. 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 comprise 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. The online supplementary material (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.

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%

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, online supplementary material, 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.

Overall, these efforts resulted in the construct of 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 (online supplementary material, 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 [59]. 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 [59]. For example, "how" often indicates prescriptive knowledge [40]. 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 Fig. 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 [61]; disruptive research may define new paths of knowledge types, by exploring the strategies and possible links between them.

Fig. 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). Fig. 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.

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.

4.6.1. 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[3]) 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,

[3] http://www.engineeringchallenges.org/challenges/cyberspace.aspx.

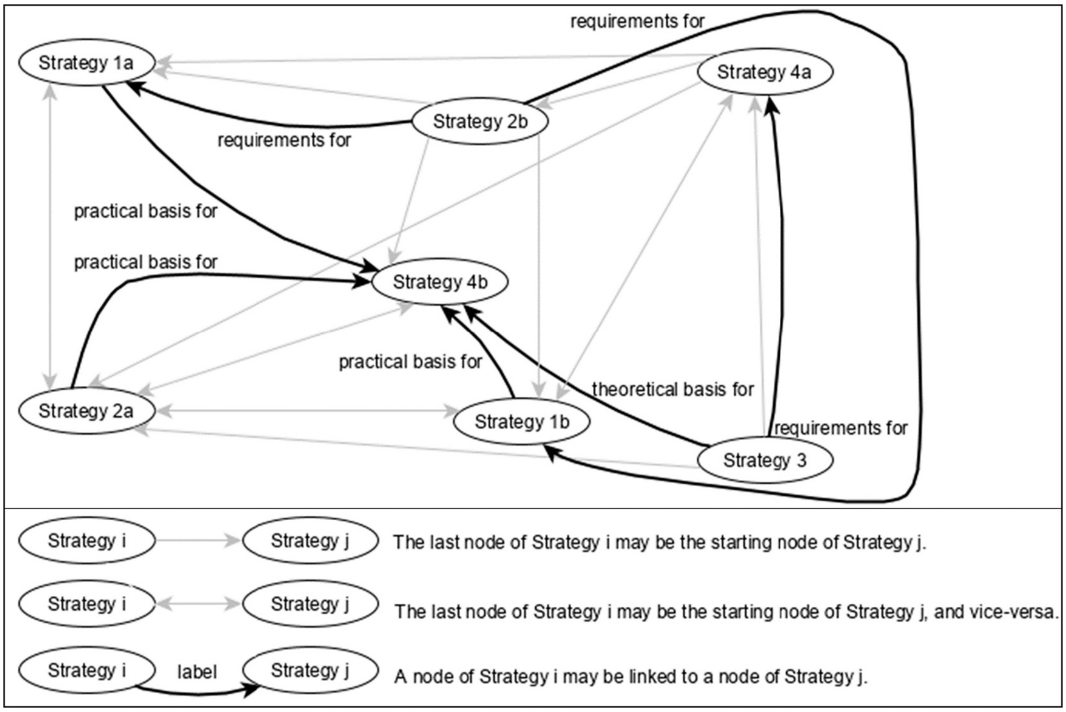

Fig. 4. Potential chaining strategies.

strategy 2a is appropriate since instantiations are a major knowledge contribution in this strategy and engrained in practice (Table 8).

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.

4.6.2. 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 $\text{N Presc} \xrightarrow{\textit{requirements for}} \text{N Desc}$. N Desc is the adversary model, whose requirements are derived from the literature review. The path is then continued as: $\text{N Desc} \xrightarrow{\textit{theoretical basis for}} \text{N Presc}$. This is similar to Arnott [62], 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: $\text{N Presc} \xrightarrow{\textit{completed with}} \text{N Presc}$. They examine the corresponding exemplar [63] 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 ($\text{N Presc} \xrightarrow{\textit{applied}} \text{I Presc}$). However, an option to generate a richer path is to build a prototype and then apply it to an example:

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

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 ($\xrightarrow{\textit{precedes}} \text{N Presc} \xrightarrow{\textit{applied}} \text{I Presc}$), 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:

$$\text{N Presc} \xrightarrow{\textit{requirements for}} \text{N Desc} \xrightarrow{\textit{theoretical basis for}} \text{N Presc} \xrightarrow{\textit{tested or implemented}} \text{I Presc} \xrightarrow{\textit{applied}} \text{I Presc}$$

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.

4.6.3. Application of guideline G3

Assume an initial knowledge contribution, with researchers wishing to pursue further research. Koch et al. [64], 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:

$$\text{I Presc} \xrightarrow{\textit{practical basis for}} \text{I Expl}$$

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, $\text{I Presc}\xrightarrow{\textit{applied}}$, 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:

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

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:

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

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 ($\text{I Presc}\xrightarrow{\textit{applied}}$ 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:

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

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

4.6.4. 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:

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

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. [65], and move to this node. Contrary to Chen et al. [65], 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:

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

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. [65]. 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:

$$\text{I Presc} \xrightarrow{\textit{practical basis for}} \text{I Expl} \xrightarrow{\textit{precedes}} \text{N Presc} \xrightarrow{\textit{principles for}} \text{I Presc} \xrightarrow{\textit{practical basis for}} \text{N Expl} \xrightarrow{\textit{requirements for}} \text{N Presc} \xrightarrow{\textit{applied}} \text{I Presc}$$

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 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 and 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 [30], except for some recent initiatives [3]. Knowledge accumulation requires integration of behavioral and design perspectives [66] and conceptual and empirical perspectives [30].

The paths of knowledge types specifically capture dynamic and pluralistic contributions as characterized by knowledge goals and knowledge scope (conceptual/nomothetic versus empirical/idiographic). The paths also provide the transparency and preciseness needed for knowledge accumulation [30]. Following the nodes in the paths of knowledge types refines the communication work of Gregor and Hevner [10] because it suggests a natural order for presenting contributions. A main contribution is the *path of knowledge types* artifact,

$$\text{N Def} \xrightarrow{\textit{constructs for}} \text{N Desc} \xrightarrow{\textit{completed with}} \text{N Presc} \xrightarrow{\textit{applied}} \text{I Presc}$$

Fig. 5. Path of knowledge types for this paper.

which we use to represent prior research and derive strategies and guidelines. Our work (this paper) pertains to strategy 1b as shown in Fig. 5.

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.

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 Journals 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 [36]. For DSR, it might even be possible to accumulate knowledge contributions in a repository of successful paths. Information systems development deals with complexity [68]. The next generation of DSR will, undoubtedly, deal with increasing complexity [69]. Acknowledging the different contributions of a project as it

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	What our work adds
March and Smith [8]; Hevner et al. [9]	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 [31]	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 [10]	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 [37]	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 [29]	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 [2]. 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.
vom Brocke et al. [3]	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	What our work adds
Iivari [25]	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.
Peffers et al. [67]	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.

progresses should help deal with such complexity and take a granular view of knowledge development [70].

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.

Credit author statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

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