Design Science in Information Systems Research

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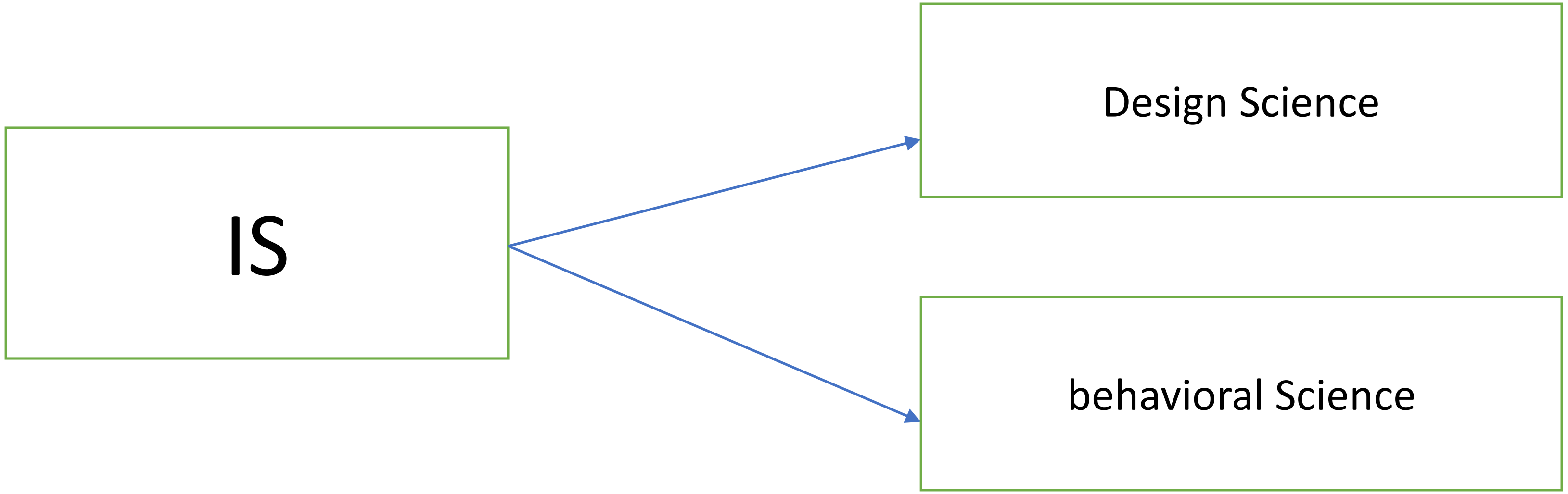
What is IS?

- information system, an integrated set of components for collecting, storing, and processing data and for providing information, knowledge, and digital products.
- Personal computers, smartphones, databases, and networks are just some examples of information systems.


IS
Design Science
behavioral Science

Behavioral Science

- The behavioral-science paradigm seeks to develop and verify theories that explain or predict human or organizational behavior.
- Examples of behavioral sciences include psychology, psychobiology, anthropology, and cognitive science.

Design Science

- The design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts.

- A general understanding of artifact in Design Science Research is that it is an object made by humans with the intention that it is used to address a practical problem.
- Both paradigms are foundational to the IS discipline, positioned as it is at the confluence of people, organizations, and technology.

Introduction

- Information systems are implemented within an organization for the purpose of improving the effectiveness and efficiency of that organization.
- We argue that acquiring such knowledge involves two complementary but distinct paradigms, behavioral science and design science.

Roots

- B-S : The behavioral-science paradigm has its roots in natural science research methods. It seeks to develop and justify theories(i.e., principles and laws) that explain or predict organizational and human phenomena sur-rounding the analysis, design, implementation, management, and use of information systems.
- D-S : The design-science paradigm has its roots in engineering and the sciences of the artificial (Simon 1996). It is fundamentally a problem-solving paradigm.

- Such artifacts are not exempt from natural laws or behavioral theories. To the contrary, their creation relies on existing kernel theories that are applied, tested, modified, and extended through the experience, creativity, intuition, and problem solving capabilities of the researcher.
- However, designing useful artifacts is complex due to the need for creative advances in domain areas in which existing theory is often insufficient.

IT artifacts?

- The resultant IT artifacts extend the boundaries of human problem solving and organizational capabilities by providing intellectual as well as computational tools. Theories regarding their application and impact will follow their development and use.
- Bundles of hardware infrastructure, software applications, informational content, and supporting resources that serve specific goals and needs in personal or organizational contexts.

IT artifacts?

- IT artifacts are broadly defined as constructs (vocabulary and symbols),models (abstractions and representations),methods (algorithms and practices), and instantiations (implemented and prototype systems).

Primary goal

- The primary goal of this paper is to inform the community of IS researchers and practitioners of how to conduct, evaluate, and present design-science research. We do so by describing the boundaries of design science within the IS discipline via a conceptual framework for understanding information systems research and by developing a set of guidelines for conducting and evaluating good design-science research.

A Framework for IS Research

- To achieve a true understanding of and appreciation for design science as an IS research paradigm, an important dichotomy must be faced. Design is both a process (set of activities) and a product (artifact) verb and a noun (Walls et al.1992)

- *The design process is a sequence of expert activities that produces an innovative product (i.e., the design artifact). The evaluation of the artifact then provides feedback information and a better understanding of the problem in order to improve both the quality of the product and the design process. This build-and-evaluate loop is typically iterated a number of times before the final design artifact is generated (Markus et al. 2002).

March and Smith (1995)

- March and Smith (1995) identify two design processes and four design artifacts produced by design-science research in IS. The two processes are build and evaluate. The artifacts are constructs, models, methods, and instantiations.
- Purposeful artifacts are built to address heretofore unsolved problems.

Constructs

- Constructs provide the language in which problems and solutions are defined and communicated (Schˆn 1983).

Models

- Models use constructs to represent a real world situation design problem and its solution space.

Methods

- Methods define processes. They provide guidance on how to solve problems, that is, how to search the solution space. These can range from formal, mathematical algorithms that explicitly define the search process to informal, textual descriptions of best practice approaches, or some combination.

Instantiations

- Instantiations show that constructs, models, or methods can be implemented in a working system. They demonstrate feasibility, enabling concrete assessment of an artifacts suitability to its intended purpose. They also enable researchers to learn about the real world, how the artifact affects it, and how users appropriate it.

Business need

- Given such an articulated business need, IS research is conducted in two complementary phases. Behavioral science addresses research through the development and justification of theories that explain or predict phenomena related to the identified business need. Design science addresses research through the building and evaluation of artifacts designed to meet the identified business need.

Truth vs utility

- The goal of behavioral-science research is truth. The goal of design-science research is utility. As argued above, our position is that truth and utility are inseparable. Truth informs design and utility informs theory.

Methodologies

- The knowledge base provides the raw materials from and through which IS research is accomplished. The knowledge base is composed of foundations and methodologies.
- Methodologies provide guidelines used in the justify/evaluate phase
- In behavioral science, methodologies are typically rooted in data collection and empirical analysis techniques.
- In design science, computational and mathematical methods are primarily used to evaluate the quality and effectiveness of artifacts; however, empirical techniques may also be employed.

Contributions

- A justified theory that is not useful for the environment contributes as little to the IS literature as an artifact that solves a nonexistent problem.

Routine design vs design research

- One issue that must be addressed in design-science research is differentiating routine design or system building from design research. The difference is in the nature of the problems and solutions. Routine design is the application of existing knowledge to organizational problems, such as constructing a financial or marketing information system using best practice artifacts (constructs, models, methods, and instantiations) existing in the knowledge base. On the other hand, design-science research addresses important unsolved problems in unique or innovative ways or solved problems in more effective or efficient ways. The key differentiator between routine design and design research is the clear identification of a contribution to the archival knowledge base of foundations and methodologies.

Wicked problems in D-S

- unstable requirements and constraints based upon ill-defined environmental contexts
- complex interactions among subcomponents of the problem and its solution
- inherent flexibility to change design processes as well as design artifacts (i.e.,malleable processes and artifacts)
- a critical dependence upon human cognitive abilities (e.g., creativity) to produce effective solutions
- a critical dependence upon human social abilities (e.g., teamwork) to produce effective solutions

Guidelines for Design Science in Information Systems Research

- As discussed above, design science is inherently a problem solving process. The fundamental principle of design-science research from which our seven guidelines are derived is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artifact. That is, design-science research requires the creation of an innovative, purposeful artifact (Guideline 1) for a specified problem domain (Guideline 2). Because the artifact is purposeful, it must yield utility for the specified problem. Hence, thorough evaluation of the artifact is crucial (Guideline 3). Novelty is similarly crucial since the artifact must be innovative, solving a heretofore unsolved problem or solving a known problem in a more effective or efficient manner (Guideline 4).

Continue…

- In this way, design-science research is differentiated from the practice of design. The artifact itself must be rigorously defined, formally represented, coherent, and internally consistent (Guideline 5). The process by which it is created, and often the artifact itself, incorporates or enables a search process whereby a problem space is constructed and a mechanism posed or enacted to find an effective solution (Guideline 6). Finally, the results of the design-science research must be communicated effectively (Guideline 7) both to a technical audience (researchers who will extend them and practitioners who will implement them) and to a managerial audience (researchers who will study them in context and practitioners who will decide if they should be implemented within their organizations).

Table 1. Design-Science Research Guidelines

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Design Evaluation

- Evaluation is a crucial component of the research process.
- The business environment establishes the requirements upon which the evaluation of the artifact is based.
- As in the justification of a behavioral science theory, evaluation of a designed IT artifact requires the definition of appropriate metrics and possibly the gathering and analysis of appropriate data.

Design Evaluation

- designed artifacts may be mathematically evaluated. As two examples, distributed database design algorithms can be evaluated using expected operating cost or average response time for a given characterization of information processing requirements (Johansson et al. 2003) and search algorithms can be evaluated using information retrieval metrics such as precision and recall (Salton 1988).

Table 2. Design Evaluation Methods	
1. Observational	Case Study: Study artifact in depth in business environment
	Field Study: Monitor use of artifact in multiple projects
2. Analytical	Static Analysis: Examine structure of artifact for static qualities (e.g., complexity)
	Architecture Analysis: Study fit of artifact into technical IS architecture
	Optimization: Demonstrate inherent optimal properties of artifact or provide optimality bounds on artifact behavior
	Dynamic Analysis: Study artifact in use for dynamic qualities (e.g., performance)
3. Experimental	Controlled Experiment: Study artifact in controlled environment for qualities (e.g., usability)
	Simulation – Execute artifact with artificial data
4. Testing	Functional (Black Box) Testing: Execute artifact interfaces to discover failures and identify defects
	Structural (White Box) Testing: Perform coverage testing of some metric (e.g., execution paths) in the artifact implementation
5. Descriptive	Informed Argument: Use information from the knowledge base (e.g., relevant research) to build a convincing argument for the artifact's utility
	Scenarios: Construct detailed scenarios around the artifact to demonstrate its utility

- The evaluation of designed artifacts typically uses methodologies available in the knowledge base. These are summarized in Table 2. The selection of evaluation methods must be matched appropriately with the designed artifact and the selected evaluation metrics. For example, descriptive methods of evaluation should only be used for especially innovative artifacts for which other forms of evaluation may not be feasible.

Design as a Search Process

- Design science is inherently iterative. The search for the best, or optimal, design is often intractable for realistic information systems problems. Heuristic search strategies produce feasible, good designs that can be implemented in the business environment.
- Design is essentially a search process to discover an effective solution to a problem.
- Abstraction and representation of appropriate means, ends, and laws are crucial components of design-science research.

Means – Ends - Laws

- Means are the set of actions and resources available to construct a solution.
- Ends represent goals and constraints on the solution.
- Laws are uncontrollable forces in the environment.

- Design-science research often simplifies a problem by explicitly representing only a subset of the relevant means, ends, and laws or by decomposing a problem into simpler subproblems. Such simplifications and decompositions may not be realistic enough to have a significant impact on practice but may represent a starting point.

The use of heuristics

- The use of heuristics to find good design solutions opens the question of how goodness is measured. Different problem representations may provide varying techniques for measuring how good a solution is. One approach is to prove or demonstrate that a heuristic design solution is always within close proximity of an optimal solution. Another is to compare produced solutions with those constructed by expert human designers for the same problem situation.

Application of the Design Science Research Guidelines

- Gavish and Gerdes (1998), which develops techniques for implementing anonymity in Group Decision Support Systems (GDSS) environments

- Aalst and Kumar (2003), which proposes a design for an eXchangeable Routing Language (XRL) to support electronic commerce workflows among trading partners
- Markus, Majchrzak, and Gasser (2002), which proposes a design theory for the development of information systems built to support emergent knowledge processes

Discussion and Conclusions

- Philosophical debates on how to conduct IS research (e.g., positivism vs. interpretivism) have been the focus of much recent attention (Klein and Myers 1999; Robey 1996; Weber 2003). The major emphasis of such debates lies in the epistemologies of research, the underlying assumption being that of the natural sciences. That is, somewhere some truth exists and somehow that truth can be extracted, explicated, and codified. The behavioral-science paradigm seeks to find what is true. In contrast, the design-science paradigm seeks to create what is effective. While it can be argued that utility relies on truth, the discovery of truth may lag the application of its utility. We argue that both design-science and behavioral-science paradigms are needed to ensure the relevance and effectiveness of IS research. Given the artificial nature of organizations and the information systems that support them, the design-science paradigm can play a significant role in resolving the fundamental dilemmas that have plagued IS research: rigor, relevance, discipline boundaries, behavior, and technology (Lee 2000).