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METHODOLOGICAL NOTE

Design Principles Unveiled: Capturing Design Knowledge from Design Science Research

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Imagine us following the design science paradigm (see Romme, 2023) to design an innovative digital platform to address sustainability transformation, and we do so by applying the design science research methodology (see Schoormann, et al., 2024). The platform has been evaluated, refined, and reevaluated. We have learned much during the research, but how should we articulate the knowledge so that other innovation researchers can benefit from it, paving the paths for future design breakthroughs? The answer is by using design principle.

WHAT IS A DESIGN PRINCIPLE?

A design principle encapsulates knowledge about creating other instances of sociotechnical artifacts that belong to the same class (cf. Sein et al., 2011). This definition highlights three key characteristics: knowledge capture, sociotechnical focus, and boundary condition. First, a design principle embodies the knowledge of what to create in an artifact and, to some extent, how to create it based on empirical evidence. The artifact could be a piece of software, an embedded system, an innovative service offering, or any of the numerous products emerging from research within the design science research paradigm (Romme, 2023). The empirical evidence is usually gathered during our own experience in designing and evaluating an artifact, but we can also learn vicariously, gathering the empirical evidence by observing innovation research team at work as well as their artifact (cf. Maedche, et al., 2021).

Second, the knowledge concerns not only the technical aspects of an artifact, but also its social aspects, such as user characteristics and organizational culture. Finally, a design principle is not universally applicable but is tailored to certain boundary conditions, such as a specific class of artifact or application context, such as a recommender system (class), a particular climate condition (context), or a specific target group (user characteristic).

Other concepts related to design principles include design patterns, design hints, design rules, and design guidelines. The concept of design patterns was popularized in Computer Science by Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides in 1995, although it was originally introduced by Christopher Alexander (1979). Design patterns provide recurring solutions to common problems within a specific context, offering a template that can be reused in various scenarios. The notion of design hints is more straightforward, offering practical suggestions or guidelines to assist designers in creating successful systems (Lampson, 1983). Similarly, terms like design rules (Norman, 1983) and design guidelines (Brown, 1998) also refer to guidance for designers to achieve effective and efficient designs.

When comparing these concepts, striking similarities emerge in their underlying ideas—guiding designers in making informed design decisions. Design principles nevertheless stand out from the rest for explicitly recognizing the boundary conditions of its application and the sociotechnical focus for the artifacts, guiding what to create and under what circumstances. Design patterns offer reusable solutions to recurring design problems, serving as templates for implementation. Design guidelines, hints, and rules vary in specificity, from general advice to strict constraints, helping designers make informed decisions.

Table 1. Comparative example for design principle, design pattern, and design rule (adopted from Seidel, et al., 2018).

Concept	Example
Design principle	Provide novel information in the form of environmental facts, observations or general behavior, so that the system affords users to experience disruptive ambiguity and surprise in sustainability transformations.
Design pattern	When users interact with sustainability content, the system occasionally presents surprising, verified facts (e.g., “Producing one cotton T-shirt requires about 2,700 liters of water.”) to spark curiosity and engagement.
Design rule	Every sustainability-related fact displayed in the system must be sourced from peer-reviewed studies or official reports (e.g., IPCC, UNEP) and include a citation.

WHAT ARE DESIGN PRINCIPLES GOOD FOR?

Design principles are invaluable for codifying design knowledge, capturing the sociotechnical aspects of an artifact, and navigating the unknown in design

science research. Consider design principles as a vehicle for codifying the knowledge generated through design science research and other experimental innovation methods to facilitate future design breakthroughs. As Van Aken (2004, p. 9) defines, design knowledge is simply "knowledge that can be used to produce designs." This knowledge can be represented in various forms, ranging from text—as is typical for design principles—to other sensory forms. For instance, an orchestra conductor might use musical notes alongside an audio recording of previous interpretations to guide a rehearsal.

As innovation researchers, we are equally concerned with the technical and social design of our artifacts. Design principles encapsulate not only what and how to design the technical aspects but also the social context in which the artifact will be used, and the potential interactions users will have with it (see the next section). Design science projects unfold at the intersection of the known and the unknown (Le Masson, Dorst, & Subrahmanian, 2013). Designing an artifact involves confronting the unknown—how it will look, how it will behave in specific contexts, and how users will interact with it remain unknown until the idea is made tangible in sketches, models, and prototypes. However, with design principles, we are not navigating this uncertainty empty-handed; instead, we are equipped with a guide that offers some direction.

HOW DO WE ARTICULATE DESIGN PRINCIPLES?

Recall the three key characteristics of a design principle: knowledge capture for reuse, sociotechnical focus, and boundary condition. The following schema reflects these characteristics and provides a template for articulating design principle:

Table 2. A simplified overview of the anatomy of a design principle (Gregor, et al., 2020) in comparison with the CIMO logic (Denyer, et al., 2008) and how to articulate each component in a design principle.

The Anatomy Component	CIMO Logic	How to articulate
Aim and Stakeholder	Outcome (O)	In order to achieve, (or allow) Aim A for Stakeholder S
Context, Boundary conditions	Context (C)	in context C
Mechanisms (encapsulated in an artifact)	Intervention (I) Mechanism (M)	Employ mechanisms M1, M2, M3….
Rationale	-	because of reasons R……

The schema demonstrates that each design principle has a stakeholder associated with the aim, in which case the purpose of the design principle may be to allow this stakeholder to engage in further activity. On the other hand, a design principle may point to different roles of stakeholders to implement some mechanisms. A mechanism describes artifact functions and characteristics as well as user strategies and actions for the accomplishment of aim. The schema also recommends the description of rationale, a justification for believing that the mechanisms will lead to achieving the aim—ideally based on empirical evidence. Finally, a design principle should clearly indicate the context in which it works, such as user characteristics, implementation settings, and other boundary conditions.

While this schema is one of the commonly used ones in design science research, there are also other templates, such as the CIMO logic (Denyer, et al., 2008). The CIMO logic is used in design science and innovation research to structure design knowledge based on context (C), intervention (I), mechanism (M), and outcome (O). The design principle schema captures all these components with the addition of the rationale component (see Table 2).

HOW DO WE CAPTURE DESIGN KNOWLEDGE INTO DESIGN PRINCIPLES?

We can capture design knowledge at any phase of design science research (Purao, et al., 2020). If formulated in the early phase based on theoretical or conceptual understanding, design principles can be reiterated and validated in the later phase. On the other hand, design principles can also serve as a product of reflection toward the end of a design science research, reminiscent of the notion of lessons learned.

In Seidel, et al. (2018), we aimed to design and implement a digital sensemaking platform to facilitate sustainability transformation in organizations. We formulated design principles based on the insights we gathered from reviewing the literature on sensemaking. For example, we found that disruptive ambiguity is an important trigger for sensemaking, and we conjectured a design principle: "*Provide environmental facts, observations or general behavior, so that the system affords users to experience disruptive ambiguity in sustainability transformations*".

The design principle was revised after several rounds of evaluation. We found that surprise was key in triggering sensemaking, and that the information provided must have a novelty value to some extent to be recognized by users. The final design principle is the one depicted in Table 1.

In the following I describe two more examples of design principle formulation in design science research

publications, starting with the innovation context before discussing one of their design principles[1].

Bartelheimer, et al. (2023) sought to increase the attractiveness of high-street retails and, ultimately, improve the livability of city centers. They designed a digital actor engagement platform featuring a seamless online-offline customer journey. Their innovation research involved many stakeholders: 150 high-street retailers and 2300 citizens. One of their design principles points to engagement connectedness, using the anatomy schema as follows:

Table 3. A design principle for digital actor engagement platforms (Bartelheimer, et al., 2023).

Design Principle 3: Engagement connectedness
Aims: Prioritize the inclusion of new complementors and consumers and remove access constraints.
Mechanisms: • Cover different channels (physical interaction, desktop PC, iOS and Android smartphones) to be inclusive for as many complementors and consumers as possible. • Provide complementors and consumers with functionality that has low requirements for personal data and allow them to switch on advanced functionality that requires more sophisticated data from them. • Personalize the engagement to explain value-in-use through campaigns, personalized offers, dashboards for consumer insights (complementors) and LBA push notifications, pulling a list of campaigns, geofencing (consumers).
Evidence-based rationale: Push and pull mechanisms need to be applied simultaneously (cf. second BIE phase); actors use different smartphones and operating systems; use of platform is subject to short-head/long-tail distribution.

Aiming to augment decision making process, Herath Pathirannehelage, et al. (2024) designed a data-driven insights platform following machine learning approaches. They collaborated closely with a fashion retailing company. After several iterations and evaluations, they captured the design knowledge in six design principles—one of them suggests the importance of continuous model learning and adaptation as follows:

Table 4. A design principle for data-driven analytics with machine learning (Herath Pathirannehelage, et al., 2024).

Design Principle 5: Design for continuous learning and adaptation
Aims: Continuous improvement over new advancements in AI technology (e.g., algorithms, hardware, data) and adaptability to changes in environment and decision-making contexts
Mechanisms: • Monitor model decay (e.g., through ML performance metrics) • Embrace an iterative process to overcome various challenges and uncertainties that may arise in different stages of AI design and deployment. As data is accumulated over time, AI models and corresponding use cases need to be updated and improved iteratively
Evidence-based rationale: The development of AI is a staged process, and as data is accumulated over time, AI models and corresponding use cases need to be adapted. An AI model's effectiveness increases when various users engage with it and the system improves over time. If use is restricted, opportunities to update become limited.

Other innovation research projects which use design principles vary in context and purpose, from wildlife management analytics (Pan, et al., 2020), mobile stress assessment (Bonenberger, et al., 2023), sensemaking platform for sustainability (Seidel, et al., 2018), responsible digital cognitive clones (Golovianko, et al., 2023), and infectious disease management (Molla, et al., 2024).

FINAL REMARKS

This primer contributes to the broader discourse in CERN IdeaSquare Journal of Experimental Innovation by highlighting how design knowledge can be systematically accumulated and evolved through design principles. This primer conceptualizes design principles as both outcomes and instruments of design science research informed by theories, prior works, and designer's own experience. Such knowledge serves as foundation for further inquiry and experimentation-driven innovation research.

Design principles are not static prescriptions, but evolving guidance shaped through cycles of articulation, application, reflection, and refinement. Their value lies not only in what they codify, but in how they invite designers to engage their own expertise and judgment. As Caussimon (2017, p. 1) suggests in the culinary domain, one must "read recipes with a passionate approach and make them your own"—so too with design principles.

FURTHER READING

Schoormann, T., Möller, F., Chandra Kruse, L., & Otto, B., 2024, BAUSTEIN – A Design Tool for Configuring and Representing Design Research, *Information Systems*

[1] Note the intention of providing an overview, recognizing the importance of considering the dependencies within a set of design principles.

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