CERN IdeaSquare Journal of Experimental Innovation, 2023; 7(2): 4-7
DOI: https://doi.org/10.23726/cij.2022.1427

METHODOLOGICAL NOTE

Design science as experimental methodology in innovation and entrepreneurship research: A primer

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WHAT IS DESIGN SCIENCE?

As a research methodology, *design science* operates at the interface of creative design and explanatory science to create and test innovative solutions. Design Science (DS) methodologies have emerged in various disciplines such as information systems (Hevner et al., 2004), operations management (Holmström et al., 2009), innovation management (Romme & Holmström, 2023), and entrepreneurship (Dimov et al., 2023). A major source of inspiration for the rise of DS is Simon's monograph (1969) *The Sciences of the Artificial*. DS is a broadly applicable methodology because it can be applied to tangible artifacts (e.g., hardware and software), intangible artifacts (e.g., innovation processes and team collaboration), or combinations of the two (e.g., a system for creating deep-tech ventures). Moreover, it can draw on a diverse set of (semi)experimental and related methods for collecting and analysing (qualitative and/or quantitative) data, which also enables its application to innovation settings in which the number of observations and cases initially is rather small.

DS therefore differs from action research by focusing on solutions as artifacts as well as adopting a broader and more flexible approach to data collection and analysis. DS also goes beyond merely problem-solving, because it draws on evidence-based protocols and also fuels theory development (Holmström et al., 2009).

WHAT IS DESIGN SCIENCE GOOD FOR?

DS is especially useful for scholars who deliberately seek to have both practical and theoretical impact in their field. For example, DS research served to develop tools and frameworks such as the Business Model Canvas (by Alex Osterwalder c.s.) and the Effectuation framework (by Saras Sarasvathy), which today are both widely used by practitioners as well as scholars in the field of entrepreneurship (for more info: Romme & Reymen, 2018). Accordingly, DS starts from a scientific mindset that seeks to deeply understand the causal mechanisms of 'how things are' *as well as* a creative design mindset that allows for exploring 'how things could be' (Simon, 1969).

Evidently, individual scholars rarely excel in both science and design because each requires fundamentally different competences. DS therefore works especially well for interdisciplinary teams in which, for instance, physicists, electrical engineers, computer scientists, industrial designers, and other experts collaborate to create and test new deep-tech solutions (Romme, 2022) or practitioner-academic teams in which business incubation professionals, organization design experts and entrepreneurship scholars collaborate to develop advanced incubation systems (Van Burg et al., 2008).

HOW TO USE DESIGN SCIENCE?

Figure 1 provides an overview of a typical DS cycle (Pascal et al., 2013; Romme & Reymen, 2018). Design and science are complementary activities in this figure. Key design steps are:

- Develop *design propositions* (e.g., from the literature) as well as *design requirements*. Design propositions can be formatted in terms of context, actions, mechanisms, and outcomes—the so-called CAMO format (Romme & Dimov, 2021). Design requirements include functional requirements as well as (e.g., practical) boundary conditions formulated by lead users.
- *Create new solutions*—for example, new technology (components) or other artifacts such as innovation management tools—informed by the design propositions and requirements formulated earlier. This step can also draw on a broad variety of other methods, for example, brainstorming, idealized design, artificial intelligence, and so forth (Romme & Dimov, 2021).

The steps in the science segment of Figure 1 are to test the proposed solution(s) and theorize about the underlying mechanisms and conditions:

- *Testing* comes in two forms in DS. Alpha-tests involve initial assessments of the solution against criteria such as usefulness, consistency, speed, robustness, feasibility, or viability; if the solution proposed does not meet such basic criteria, one typically returns to one of the previous steps. Beta-tests may further improve the legitimacy of the (alpha-tested) solution, by assessing it against criteria such as generalizability, reliability, and internal and external validity; pre-test/post-test experimental methods are often used here (Meulman et al., 2018). However, many DS projects do not engage in beta-testing but directly proceed to implementing the solution, especially when the problem is a pressing one and no viable alternative solution is available; the performance of the implemented solution then, in fact, constitutes the beta-test.

- The *theorizing* step serves to reflect on the solution(s) created and tested, in terms of the underlying theoretical mechanisms, outcomes, and boundary conditions. This step may also kickstart the DS cycle by, for instance, conducting a systematic review of the literature from which design propositions are inferred (see above).

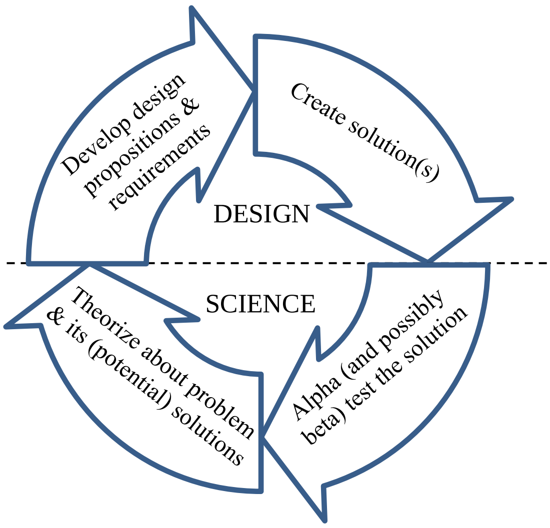

Fig. 1. Overview of a typical DS cycle.

DS typically involves many iterations back and forth within this (or a similar) DS cycle. Examples of studies drawing on this type of cycle are Meulman et al. (2018), Baldassarre et al. (2020), Peltokorpi et al. (2019) and Hyytinen et al. (2022). The review paper by Romme and Dimov (2021) also contains several other examples. The book by Dresch et al. (2015) provides a good overview of DS, one that is also useful for teaching it.

To illustrate the application of DS, I outline a recent study by Romme et al. (2023), in which we designed and tested the blueprint of a Deep-Tech Venture (DTV) builder. Deep-tech innovations arise from scientific and technological breakthroughs in, for example, new materials, photonics, mechatronics, high-precision engineering, and artificial intelligence. These innovations are critical in addressing grand challenges such as climate change and energy storage. However, DTVs have to overcome the so-called valley of death, which causes the vast majority of these ventures to fail (Romme et al., 2023). We therefore adopted a DS research cycle.

We started by *theorizing about* the valley of death for DTVs as the main problem and its potential solutions, by conducting a systematic review of the literature. Informed by the latter review, we subsequently formulated an initial *design proposition*: "An integrated system for building DTVs that provides the best possible conditions, resources and processes for creating and developing these ventures serves to effectively bridge the (major risks arising from) the broad and deep valley of death for DTVs" (Romme et al., 2023). The key *design requirement* formulated was that the DTV building approach to be designed "has to capitalize on the key strengths of the regional (deep-tech) ecosystem in and around Eindhoven" (Romme et al., 2023).

Based on this design proposition and requirement, a *solution was iteratively created and alpha-tested*, in terms of a design for DTV building implemented by HighTechXL. Figure 2 provides an overview of this so-called system design that involves various components in two major subsystems: (a) the key conditions and resources for building DTVs and (b) the DTV journey itself. The key conditions and resources constitute the most distinctive elements, given that almost all existing venture builders focus on the venturing process and do not deliberately invest in creating optimal conditions and resources (Romme et al., 2023).

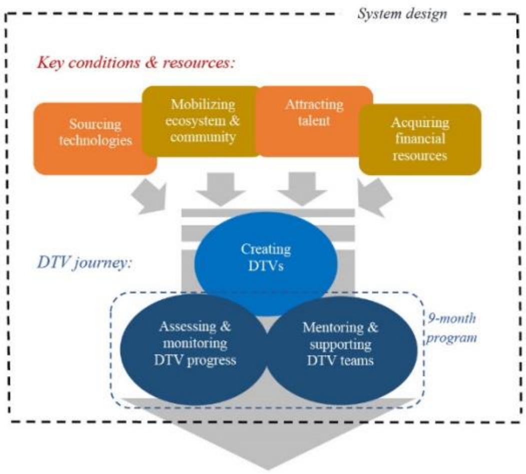

Fig. 2. System design of HighTechXL as deep-tech venture builder (source: Romme et al., 2023).

Within the two subsystems outlined in Figure 2, we developed various processes and tools for sourcing breakthrough technologies from leading research institutes (such as CERN and European Space Agency); exploiting the deep-tech ecosystem around leading companies such as ASML, NXP and Philips; recruiting talent for creating venture teams; designing an investment vehicle for funding DTVs; developing a stage-gated process for guiding ventures and selecting the most promising ones (to proceed to the next stage); and various other processes and tools. Most of these tools and process designs for specific resources and processes in Figure 2 were designed and alpha-tested via graduate projects conducted by MSc students (from an adjacent university); the subsequent beta-testing was done by applying these solutions structurally to the technologies sourced and the ventures created from them (Romme et al., 2023). An example is the tool for structurally aligning a venture value proposition to one of the Sustainable Development Goals of the United Nations (Schutselaars et al., 2023).

The *ultimate (beta) test* of the system design outlined in Figure 2 is still ongoing. However, Romme et al. (2023) do report a preliminary assessment of HighTechXL's performance with regard to the 26 ventures created in the period 2019-2022. This performance is assessed in terms of the progress these ventures have been making, measured in Technology Readiness Levels (for more details: Romme et al., 2023).

Finally, we also *theorized* about the design solution outlined in Figure 2, in terms of how it differs from other venture builders, its boundary conditions, and its applicability elsewhere in Europe. As such, this DTV building approach is rather unique in the sense that it directly sources deep-tech inventions from leading research institutes and also attracts various types of talents to create venture teams from scratch. This blueprint for building DTVs also capitalizes on the deep-tech ecosystem available in the Eindhoven region in The Netherlands (Romme, 2022). The presence of such an ecosystem thus constitutes the primary boundary condition for applying this blueprint elsewhere (Romme et al., 2023).

In sum, this application illustrates how DS serves to create and test innovative solutions at the interface of creative design and explanatory science. By focusing on solutions as artifacts, DS goes beyond other research approaches, such as action research. Moreover, by drawing on evidence-based methods and design propositions, DS is also distinct from (creative) design thinking and other problem-solving methods.

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