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Advancing Design through Science and Research

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INTRODUCTION

Design is a fundamental human activity that creates and shapes the human-made world, which in turn shapes human experience and agency. Both human agency and structure constitute this creative practice (Auernhammer & Hall, 2014). The professionalization of this practice through a body of knowledge and embodied activities allows the creation of artifacts, such as graphics, products, services, and urban environments, that are produced and used at scale. Therefore, this practice influences the natural world by utilizing and transforming resources and raw materials to address individual and societal needs. Advancing this practice to address societal and environmental challenges is essential for the survival of all living species (Fuller, 1969; Neutra, 1954; Papanek, 1973).

IS THERE A SCIENCE OF DESIGN?

Advancing this professional practice of Design involves developing the body of Design knowledge through Science and Research. In 1947, Walter Gropius (1955) asked the fundamental question: "Is there a Science of Design?[1]" For him, Design broadly embraces the whole orbit of human-made (visible) surroundings, from simple everyday goods to the complex pattern of a whole town, while Science is the creation of knowledge relevant to Design. Gropius (1955) outlined three primary Sciences of Design, as shown in Figure 1.

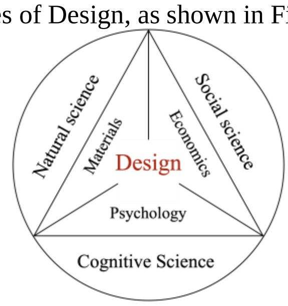

Fig. 1. The Primary Sciences of Design, based on Gropius (1955).

These primary sciences are the material problems of structure (natural science), economy (social science), and psychological experiences (cognitive science). The knowledge from the Natural Sciences informs Design practices that address structural and technological challenges. This knowledge is imperative for the reliability, quality, and sustainability of the design and physiological well-being of living organisms. The knowledge from the Social Sciences informs the resource allocation for the creation and production of designed artifacts. Understanding the socioeconomic dynamics in the interrelation of interests of clients, funders, policymakers, administrators, designers, and diverse groups in the general public is imperative to navigate governance, project organization, and design outcomes (Rittel & Webber, 1973). Gropius (1955, pp. 30-33) also highlighted the importance of psychology as essential in Design as follows:

> "Most important is the fact that sensation comes from us, not from the object which we see. If we can understand the nature of what we see and the way we perceive it, then we will know more about the potential influences of [hu]man-made design on human feelings and thinking. […] If the design is to be a specific language of communication for the expression of subconscious sensations, it must have its own elementary codes of scale, form, and color. It needs its own grammar of composition to integrate these elementary codes into messages which, expressed through the senses, link [hu]man to [hu]man even closer than to words."

Developing the body of knowledge of psychological processes, including perception, thinking, interactions, and behavior, informs the Design practices, such as the perceptive, creative, imaginative, and expressive, of conception (i.e., design thinking[2]) in collaborative acts, as well as the perception, interpretation, and interaction of people with an artifact (i.e., design communication). Such knowledge is imperative in designing experiential aspects, including aesthetics, usefulness, usability, meaning, and value. Understanding the effects of optical illusions, the psychological influences of shapes, colors, and textures, the effects of contrast, direction, tension, and repose, and the significance of human scale enable

[1] First published as "Design Topics" by W. Gropius, Magazine of Art, December 1947

[2] The thinking of individuals when designing, not a methodology (Auernhammer & Roth 2023)

designers to see, define, and create experiences through their artifacts (Gropius, 1955). Gropius (1955) emphasized that these psychological experiences should be defined precisely in specific terms, and one must avoid vague phrases like "the atmosphere of a building" or "the coziness of a room." Such precise knowledge creation is imperative and can be developed through scientific investigation, i.e., a 'Science for Design.'

SCIENCE FOR DESIGN

A Science for Design is the scientific investigation to develop insights and theories essential to the practices of Design. For example, the insights from Gestalt psychology on perception and productive thinking by Max Wertheimer (1922, 1923), Wolfgang Köhler (1929), Kurt Koffka (1935), and Rudolf Arnheim (1969) informed designers, including Paul Klee (1921/22), Wassily Kandinsky (1926), László Moholy-Nagy (1947), György Kepes (1944), and Robert McKim (1972) in the development of visual grammar, language, and thinking (Behrens, 1998; Boudewijnse, 2012; Teuber, 1976). Similarly, the philosophical and experimental research by John Dewey (1910), Wolfgang Köhler (1917), Max Wertheimer (1920, 1945), Otto Selz (1922), Graham Wallas (1926), Karl Duncker (1935), and J. P. Guilford (1950) on productive and creative thinking informed designers, such as John Arnold (1959), Charles Eastman (1970), and Bryan Lawson (1972) in the development of 'design thinking' and 'design processes' (Auernhammer & Roth, 2021, 2022, 2023). Theories, developed through a 'Science for Design,' provide the body of scientific knowledge that informs designers in the development of new design practices (e.g., team dynamics) and possibilities (e.g., new material composition)[3]. To develop this kind of knowledge, there are several considerations:

- Scientific knowledge of design practices requires the examination of the phenomenon in the context of the practice of Design.
- Scientific knowledge about new possibilities in Design is based on primary research that investigates, e.g., material properties.
- Produced scientific knowledge informs and/or enables Design practices and possibilities.

The resulting scientific knowledge informs designers in the development of the body of Design knowledge. For example, knowledge of synthetic biology can inform designers in the creation of new designs by utilizing new biomaterials (Ginsberg, Calvert, Schyfter, Elfick, & Endy, 2014). For the advancement of Design knowledge, scientific knowledge needs to be enacted and evaluated to be useful in design practices (Vincenti, 1990). Such knowledge creation is grounded in Design practice. For example, scientific knowledge contributed to the development of control volume analysis in aircraft evolution (Vincenti, 1990). However, the knowledge and relevant techniques for the advancement of aircraft designs were developed in the engineering applications (Vincenti, 1990). Such knowledge creation requires 'Design Science' and 'Design Research.'

DESIGN SCIENCE / RESEARCH

Advancing the body of knowledge essential for the professional practices of Design that produce the human-made world requires the creation of new knowledge. Design knowledge is created by enacting (the act of designing) and empirically examining the design in relation to its performance, meaning, and impact in context. Such knowledge creation is based on 'Design Science' or 'Design Research.'

Design Science

Design Science is the systematic creation of knowledge through Design. It is often associated with Herbert Simon's (1969) *Science of the Artificial*. Interestingly, Herbert Simon taught economics to engineering and architecture students at the Illinois Institute of Technology in Chicago by invitation from Mies van der Rohe, which influenced him in the development of his decision theory (Simon, 1991, pp. 94-101). He later engaged in design cognition research through collaboration with his colleague, the architect Charles Eastman (1970). The fundamental idea of 'Design Science' is to investigate the relationship between a purpose and created means (de Groot, 1965; Duncker, 1935; Eastman, 1970; Selz, 1922; Simon, 1969, 1981, 2017). The determination of a means to a purpose relationship provides the knowledge to replicate the practice and structure. This productive thinking theory informed the development of the 'Science of Design' and 'Design Cognition' (Eastman, 1970; Simon, 1969, 1981). Figure 2 illustrates the determination of the purpose-means relationship through Design Science.

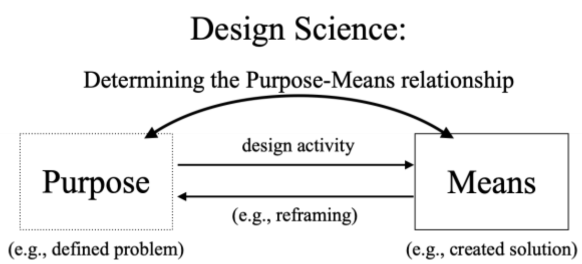

Fig. 2. Purpose-Means relationship (Selz, 1922)

[3] Science for Design corresponds with 'research into design' and 'research for design' (Stappers & Giaccardi, 2017).

This purpose-means relationship is discussed in Design and other fields in different terms, including the "form ever follows function" (Sullivan, 1896), means-end (Simon, 1969), design specifications/requirements-product (Hubka & Eder, 1996), or problem-solution (Maher & Poon, 1996). Design Science investigates the (optimal) fit of the produced design (e.g., means, form, product, action, performance, system, or solution) in relation to the intended purpose (e.g., requirements, question, goal, task, function, frame, challenge, problem, or desired state). Design Science empirically investigates whether the designed artifact (i.e., "inner environment") is fitting to the conditions (i.e., "outer environment") to determine the purpose-means relationship (Simon, 1969). The resulting knowledge is a propositional statement, including a rule, pattern, or method based on the abstract purpose-means relationship (Figure 2). Developing this kind of Design knowledge requires both Design and Science. Design practices (i.e., knowing how and the ability to act on the know-how) are required to create a design (knowing what) based on intent or purpose (knowing why). March (1976) and Roozenburg (1993) have suggested that designers determine a feasible means to the purpose abductively (Peirce's 'innovation abduction'). However, empirical examination is needed to determine the purpose-means relationship evidentially by measuring the performance of the means in relation to the defined requirements (i.e., intended purpose) through direct observation and empirical examination. Empirically determining the means to the purpose includes several considerations:

- The purpose needs to be understood, which requires identifying and defining the design specifications or requirements (knowing why).
- The means need to be developed, which requires design practice (knowing how).
- The designed means need to be ontologically understood and observable (knowing what).
- The performance of the means in relation to the intended purpose needs to be directly observed and measured (e.g., analyzing the means-end fit).
- It is not valid to propose design rules, patterns, or methods in which the purpose-means relationship has not been empirically examined and evaluated (i.e., hypothetical patterns or rules).
- The development of the body of Design knowledge is an evolutionary process as new technological possibilities allow the development of new means, advancing Design through new knowledge (Vincenti, 1990).

This systematic creation of knowledge is underpinned by a technical rational epistemology and often follows a specific methodology, such as Design Science research methodology. However, the creation of the means (designing) is a creative, iterative, and ambiguous activity in which designers often reframe or discover new requirements, overcoming fixation (Duncker, 1935). Today, the generation of means is supported through Artificial Generative Intelligence, producing a large number of (conceptual/digital) means in relation to a prompt (i.e., a purpose) and statistically determining the best fit for each means through predefined measurements. Such produced means are based on the model of trained, biased data. However, such reframing and biased means determination can be problematic as the means addresses an uninformed purpose, or AI systems produce uniformed means. Therefore, it is essential to capture and evaluate the purpose-means relationship and not just the designed means by itself.

Design Science is based on the structuralist psychology of productive thinking (de Groot, 1965; Selz, 1922). The basic theoretical conception of this psychology has been applied to science (Popper, 2002), computer science and artificial intelligence (Newell, Shaw, & Simon, 1958; Newell & Simon, 1956), engineering (Pahl & Beitz, 1977; Papalambros, 2015), information systems (Hevner, March, Park, & Ram, 2004), strategy and organization (Mintzberg, 1990; Romme, 2003; Simon, 1965), and entrepreneurship (Sarasvathy, 2001). Generally, Design Science is applicable when requirements can be defined clearly, and the relationship between means and purpose can be determined directly (i.e., the performance of the means in relation to the requirements is measurable). However, a different approach is required to develop the body of Design knowledge in situations in which purpose cannot be clearly defined and measured in situations of social or wicked problems (Lewin, 1946; Rittel & Webber, 1973).

Design Research

A different approach to developing Design knowledge is Design Research. Like Design Science, Design Research focuses on knowledge creation through Design. Design Research is understood in diverse ways. In this article, Design Research is an empirical examination of the immanent structural quality that constitutes the situation.

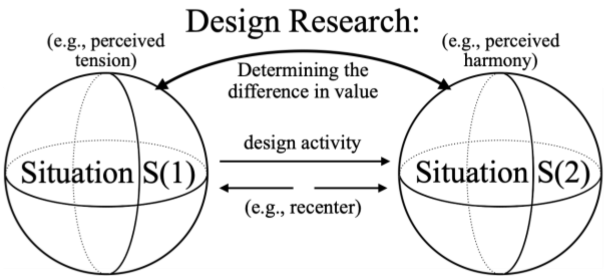

Fig. 3. Situation S(2) compared to S(1) (Wertheimer, 1945).

As illustrated in Figure 3, Design Research investigates a situation S(1) in comparison to a situation S(2). The direct examination and comparison of situations S(1) and S(2) identifies the differences in immanent structural value in which there are no fixed requirements or goals. In general, Design knowledge is created by examining the dynamic relationships that constitute the whole situation or experience (i.e., the immanent structure) produced and changed by the designed artifacts (e.g., a product). Design Research focuses on three main aspects. The first aspect is the investigation of the dynamic relationships inherent in the whole situation S(1). Secondly, it requires examining the dynamic relationships through the designed intervention that produces a whole new situation S(2). Lastly, the examination of the differences between situations S(1) and S(2) reveals the value of the design, including experience, aesthetics, feelings, emotions, value, meaning, accessibility, and sustainability. For example, Design Research allows the investigation of human aspects, such as meaning, through semiotics (Krippendorff, 1989; Maldonado, 1959).

The creation of a new value often follows a productive thought process from tension to harmony (Wertheimer, 1945). A perceived tension (i.e., need, interest, motivation, hunch) in situation S(1) drives the designer to make an intervention towards a harmonious (i.e., resolution, closure, conclusion) situation S(2) (Wertheimer, 1945). Such productive thinking is ambiguous as new immanent structural value emerges in the perception (e.g., perspective) and interaction with materials, instruments, and the environment (Wertheimer, 1945). For example, a designed artifact in S(1) is comfortable, long-lasting, and expensive. From a social inclusion perspective, this artifact is not inclusive (i.e., perceived tension). A redesigned artifact introduced in S(2) is comfortable, short-lived, and affordable. S(2) resolved the tension of social inclusion while producing tension for environmental sustainability.

Design Research empirically examines the situation S(1) in comparison to S(2) to reveal the value and potential consequences (i.e., emerging tensions) of the introduced design. Design Research needs to examine the situations S(1) and S(2) from diverse perspectives to reveal the various values from each perspective and potential value tensions between perspectives in situations of multifaceted complexity, such as urban planning or other social situations (Lewin, 1946; Rittel & Webber, 1973). For the contribution of the body of Design knowledge through Design Research, there are several considerations:

- Research needs to investigate the dynamic integration of the relationships (e.g., integration of materials, manufacturing, and aesthetics experience) that constitute the whole situation – and not individual parts (e.g., only aesthetics experience).
- Multifaceted complex situations require examining the situation holistically, i.e., from many diverse perspectives, requiring multiple groups.
- It is essential to identify the critical relationships in the integration that constitute the whole situation (the immanent structure), as it is challenging to understand every influence.
- Examining different relationships that constitute the whole situation often requires a different measurement (e.g., ergonomics aspects can be measured quantitatively, while human values require qualitative assessments).
- Design knowledge is created by empirically examining the differences in situation S(1) and situation S(2) that incorporate the designed intervention to reveal its value.
- It is not valid to suggest a difference in value (e.g., often the intent of the designer) without producing the intervention and examining the dynamic relationships within the situational circumstances.
- There is no correct, optimal, or true answer as each situation will have different inherent values and they evolve over time (e.g., changes in values in society).
- Examining the perceived tension S(1) by the designers and the many activities that result in perceived harmony S(2) examines the inherent design thinking and practice, advancing knowledge of designing (i.e., qualities, including thinking, activities, and practices).
- Examining the dynamic integration of relationships from a novel perspective can reveal a new critical aspect that has been unnoticed in previous research, which advances the body of Design knowledge.

Design Research is based on the Gestalt psychology of productive thinking (Wertheimer, 1945). It is applicable when there are no fixed problems or goals (Jones, 1991); problem and solutions are inseparable (Krippendorff, 2006); the situation can dynamically evolve (e.g., by changes in the environment) (Lewin, 1936); in social situations when there is no stable state (Schön, 1973); and when there are diverse needs and need-tensions between diverse groups in society (Lewin, 1946; Rittel & Webber, 1973).

ADVANCING DESIGN

Science for Design, Design Science, and Design Research provide different types of knowledge essential to advance the body of Design knowledge. Science for Design produced knowledge about and for Design. Design Science creates knowledge through design in technical challenges/stable situations in which the relationship between the means and a purpose can be determined (i.e., measured). Design Research creates knowledge through design in social and dynamic situations by examining the immanent structural quality in comparison with or without a specific design or in comparison between different designs. These different types of Science/Research to advance Design are illustrated in Figure 4.

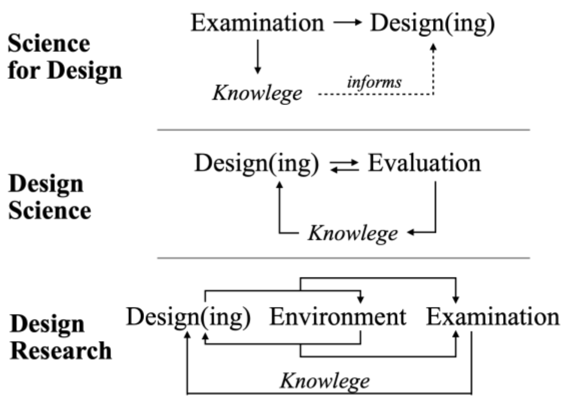

Fig. 4. Design Knowledge Creation through Science and Research.

Science for Design informs designers by providing relevant insights for their practice. For example, psychological experiments identify perceptual principles, such as Prägnanz (i.e., when a whole situation is grasped with the minimal amount of energy exerted in the thinking) or Affordance, providing insights into the perceptual organization (Gibson, 2014; Wertheimer, 1922). Such insights from psychology informed design researchers in the creation of artifacts for meaningful and intuitive experiences (Knight, 1973; Krippendorff, 1989; Norman, 2013).

Design Science focuses on searching alternative combinations of variables of means (i.e., design solution) and evaluates these alternatives to determine a fit to a set of defined parameters within a range of possible probabilities (Simon, 1969). A designed means serves its intended purpose when the designed artifact (i.e., "inner environment") is fitting to the conditions (i.e., "outer environment"). Such analysis results in knowledge of abstract purpose-means relationships and technical rules.

Design Research focuses on exploring new design combinations and integrations to identify new opportunities (e.g., technologies, materials, procedures, visual grammar, and practices) and evaluating their value (e.g., usefulness, sustainability, and joyfulness). Such research reveals the difference the designed solution makes within situational circumstances in comparison to other designs and (previous) situations. Design Research examines the value of the design within situational circumstances (from diverse perspectives) in which there is no clear purpose or there are diverse needs and need tensions (Lewin, 1936; Rittel & Webber, 1973). Such research results in Design knowledge that provides the inherent value of a particular design and design practice within a specific context.

Such knowledge creation advanced the frontiers of Design. For example, the combination of diverse knowledge led to the development of 'Modern Design' in the early 20th century. Knowledge from psychological experiments informed the development of visual grammar and language (e.g., see the Bauhaus books 1925-1930). The integration of a new visual grammar with manufacturing procedures resulted in the production of aesthetic and purposeful utilitarian designs that are uncompromised by mass production, advancing design practices (e.g., the Wassily Chair, Barcelona Chair, Zentrum in Bern, Switzerland, Weissenhof in Stuttgart, Germany, and Gropius House, Lincoln, USA). Design knowledge from psychology (cognitive science) informed the visual grammar, which, in combination with manufacturing procedures of diverse materials (natural science), resolved the socioeconomic (social science) tensions through affordable construction and production. The integration of natural, social, and cognitive sciences in Design practices drove the 'Modern Design Movement.' Such knowledge creation and integration from scientific and design research is the *Advancement of Design through Science and Research*.

ACKNOWLEDGMENT

In memory of Otto Selz, one of the most influential and unknown experimental psychologists. His fundamental idea of Productive Thinking through Purpose-Means Complexes influenced the developments in Artificial Intelligence, Evolutionary Epistemology in Science, the Science of Design, Design Thinking (problem-solution coevolution), Choice and Decision Theory, Managerial Decisions, and Organizational Theory through the work of academics such as Adriaan de Groot and Herbert Simon. He was murdered in the Auschwitz concentration camp.

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