What is the Content of "Design Thinking"? Design Heuristics as *Conceptual Repertoire*

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Abstract

When engaged in design activity, what does a designer think *about*? And how does she draw on disciplinary knowledge, precedent, and other strategies in her design process in order to imagine new possible futures? In this paper, we explore Design Heuristics as a form of intermediate-level knowledge that may explain how designers build on existing knowledge of "design moves"—non-deterministic, generative strategies or heuristics—during conceptual design activity. We describe relationships between disciplinary training and the acquisition of such heuristics, and postulate how design students might accelerate their development of expertise.

I. Introduction

When engaged in design thinking, what is a designer thinking *about*? The importance of design process as key to innovation is well established [30,37], but to get to great solutions, designers must "scope, generate, evaluate, and realize ideas" [36]. This process of realizing ideas through a range of design activities is not well understood, particularly in relation to how these abilities can be taught or developed over time [6,14]. When engaging in design activity in an educational environment, students learn to tackle design within collaborative teams by exploring a problem space with hands-on research *(what is)*, exploring a related solution space with various ideation techniques *(what if)*, and aligning the ideas with reality through repeated feedback and iteration to revise the selected paths towards a solution *(what becomes)* [26]. We will focus primarily on the ideation stage in this paper, discussing how designers explore a solution space through the generation of potential solutions, and address the nature of design cognition, or "designerly ways of knowing" [6], that makes idea exploration possible.

Design scholars have built descriptive design theory that can explain portions of the idea generation process, often pictured as a dialectic between problem and solution [4,13], where a movement between convergence and divergence [2,14], incorporation of user research to encourage the inclusion of human-centered design principles [19], framing and traversal of the problem space [12], and precedent knowledge [24,32,31] all fuel the generation of ideas. In this paper, we will account for the idea generation process in relation to designers' knowledge of existing design artifacts and design strategies (e.g., patterns, best practices, heuristics).

When engaged in design activity, a designer often chooses to add variation to conceptual designs in order to address the problem in a novel way. *Design Heuristics* captures the ways that designers modify product concepts, and are based on observed patterns of conceptual development in empirical studies of past product designs [39,40]. For example, one design strategy is to "make use of all surfaces available" when generating a design; a shelf is designed to hold objects, but also provides an underside that can serve other purposes. This strategy is captured in a *Design Heuristic*, "Use opposite surface," displayed on two sides of a card (Figure 1). In this way, knowledge about past designs can be constructively applied to new designs (as shown in the product examples). Seventy-seven separate *Design Heuristics* have been empirically identified [11], each capturing design strategies shown to be useful in past designs.

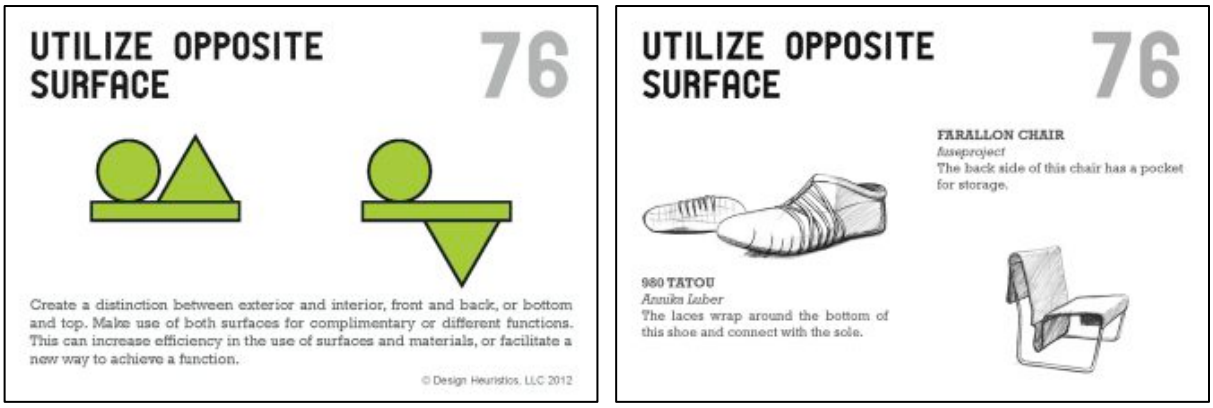

Figure 1: The Design Heuristic, "Utilize opposite surface," provides a text and a graphical description on one side of a card, and two examples of products illustrating it on the other.

Other idea generation methods (e.g., TRIZ, Synectics) describe the knowledge abstracted from an artifact or precedent in a more distilled form. These other methods are generally represented as abstract principles or framing guidelines (e.g., Synectics, SCAMPER), and others are much more specific about tradeoffs in designed artifacts (e.g., TRIZ). Unlike these methods, *Design Heuristics* capture strategic knowledge about how to generate alternative concepts that are easy to understand and apply, and are empirically grounded in precedent artifacts and design activity. *Design Heuristics* capture patterns of how to generate successful designs on an intermediate and strategic level—within a region of knowledge that Höök and Löwgren identify as "more abstracted than particular instances, yet does not aspire to the generality of a theory" [21]—linking the designer with past successful solutions.

II. Design Precedent and Intermediate-Level Knowledge

Design research indicates that successful ideation involves exploring both the problem and solution space simultaneously [13,28], as well as engaging in both divergent and convergent thinking. This means there are times in the process when designers ask many questions and generate multiple ideas for consideration, as well as times when designers narrow down the selection of their problem criteria and ideas to elaborate on the details of one (or a few) of them [4,15,18]. As in many areas of expertise, design thinking often involves analogy to past solutions, or precedents that can be usefully applied in future work [5,20,22,25].

While knowledge of precedent artifacts is relatively straightforward—as documentation of what has been created—the generation of an intermediate form of knowledge that represents the curatorial dimension above the precedent or ultimate particular level is substantially more complex and abstract. Scholars within the design community have noted that this intermediate-level form of knowledge is underdeveloped in many disciplines, as it fits neither the category of precedent artifact nor scientific theory [e.g., 29]. Two recent attempts to further develop this intermediate space are *bridging concepts* between empirically grounded theory and practical use [7], and *strong concepts*, a form of intermediate-level knowledge describing core design ideas that are inherently generative [21]. Another concept, *collections* or *annotated portfolios* [e.g., 27], reflects practices that already commonly occur in the research phase of a design process (e.g., comparative market analysis). This form of intermediate-level knowledge generation affords the generation of conceptual structures that are abstracted beyond a particular design artifact, and thus represent an approach, strategy, or generative hint towards a class of design moves, rather than a prescriptive or otherwise deterministic connection [17].

Beyond a collection of distinct designed artifacts, past research has analyzed the characteristics that bind certain design approaches together, as in Alexander's *pattern language* [1], Krippendorf's *design discourses* [23], conceptual primitives [33], or language of thought [16]. These approaches provide insight into how disciplinary knowledge might be distilled into intermediate-level knowledge, built by constructing

composite pieces that originate in situated knowledge [38]. Following this concept of *pattern language*, we posit that the content of design thinking—as a distinct human activity and epistemology [3,29]—can be identified from its appearance in situated design activity. Through close analysis of concepts created by designers, patterns of intermediate-level knowledge can be discerned, which we characterize as *Design Heuristics*.

III. *Design Heuristics* as Conceptual Repertoire

Schön [34] characterized the design process as a reflective "conversation" between the designer and the artifact being designed. Within this conversation, the designer mediates between the design project at hand, a lifetime of lived experiences, knowledge of existing solutions (i.e., precedents), and cognitive schema that relate these elements to each other [8]. Schön [35] refers to this store of precedents as a designer's *repertoire*, or a personal source of generative metaphors. More broadly, repertoire can be found in curated or canonical forms in collections of precedents (e.g., the "best designs of the year" lists), often created by experts within a given design discipline. Beyond this knowledge of the particular, an experienced designer also carries with them a *conceptual* repertoire—similar to a curated collection, yet largely buried in memory as tacit knowledge—which they are able to apply to new design problems. We propose that the use of *Design Heuristics* builds an individual designer's repertoire [35] of conceptual content capturing the ontology of design strategies facilitating idea generation. This *conceptual repertoire* represents a collection of intermediate-level knowledge that is built on experiential precedents, containing successful patterns of design reasoning that, in their formation and use, assist the designer in creating new design concepts.

A conceptual repertoire shares many similarities to Alexander's pattern language, in that patterns have classificatory or curatorial qualities that transcend individual precedents. In *Design Heuristics*, we are not only identifying potential patterns (thus building intermediate-level knowledge), but are also able to use these patterns to tie individual design concepts to a larger disciplinary canon of strategies. In Alexander's pattern language, recurring design problems are linked with canonical solutions non-deterministically; that is, as a "likely" solution given historical precedence. *Design Heuristics* make the same claim: intermediate distillations of content knowledge about designs, in particular the cataloguing of design strategies, can suggest possible solutions for the designer to explore in a non-deterministic manner [39].

In empirical studies, the use of *Design Heuristics* has been shown to scaffold the metacognitive development of early engineering students [9], and to facilitate the generation of novel concepts even in experienced designers [41]. Designers can examine a heuristic card, and successfully use the intermediate-level knowledge it contains to extend or redefine a design concept. This demonstrates their potential for linking design concepts and knowledge about idea generation in a fluid, bidirectional manner. We are proposing that a designer builds dynamic links between disciplinary canon (containing both precedents and intermediate-level knowledge of strategies) and their own conceptual repertoire (Figure 2). Over time, the heuristics become incorporated into the designer's individual repertoire.

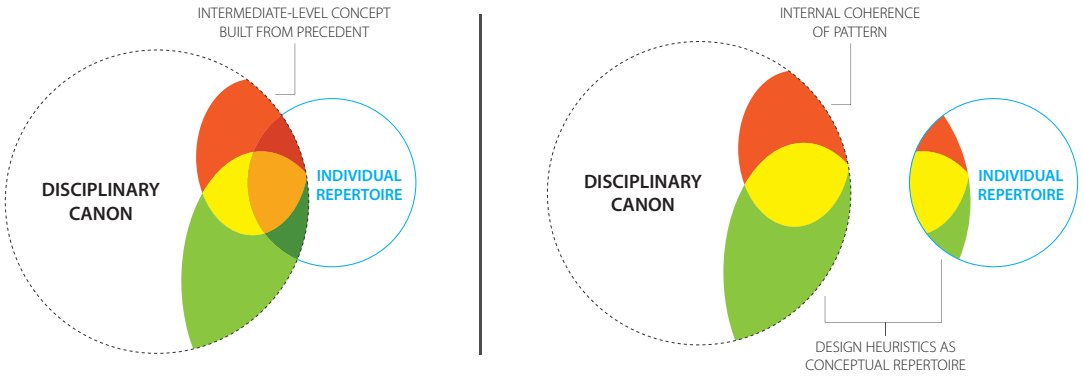

Figure 2: Relationship of the disciplinary canon and underlying conceptual repertoire to a developing designer's repertoire.

Design Heuristics translate the components or design moves used in individual concepts into an organized repertoire. Designers use this translational process to locate and document areas of internal coherence. The power of this approach comes through the nature of the intermediate-level knowledge identified—positioned between formal theory and the ultimate particular; specifically, this form of knowledge is not prescriptive (i.e., tells the designer *what* to do), but rather heuristic (i.e., makes an inductive argument established through the usefulness of previous concepts generated). The resulting intermediate-level knowledge about successful design moves demonstrates both variety of execution and an implicit argument regarding effectiveness or efficacy. *Design Heuristics* are just one of many possible articulations of precedent curation into a conceptual repertoire, and as such comprise only one form or class of intermediate-level knowledge.

Progressing one level deeper, we can explore the affordances of the *Design Heuristics* method. Different knowledge or validity claims are made by different portions of the heuristic cards. These constitute different ontological arguments, and taken together, comprise a formalization of intermediate-level knowledge. The precedent artifacts on the reverse of the card most explicitly substantiate the curatorial aspect—supporting the heuristic through physical examples, documenting ultimate particulars that led to the creation of the heuristic, or otherwise exemplify its content. The title of the heuristic is then a reification of this curation, translating the similarities between precedent instances (beyond those on the card) into a labeled concept or phenomenon. The description and simplified graphic representation, then, is a documentation of the inductive conclusion that holds the examples together—both those present on the card, and the larger empirical work on which the heuristics are based. The designer or user of the card can then make sense of and generatively use not only the heuristic, but also trace its coherence and internal validity using the variety of evidence provided.

These heuristic cards are then used by a designer through a process of abduction, with the designer responsible for selecting a heuristic and imagining how it might be used to transform or redefine an existing concept. This is the essence of the cognitive skill that permeates design: taking a stimulus, such as a *Design Heuristic*, and using it as a gambit [24] to imagine a design space where an alteration of a concept, or a new concept altogether, is possible. Thus, this translational process implicates an element of the conceptual repertoire within the known disciplinary canon, linking the designer's present context and problem space definition to that designer's own conceptual repertoire through a potential solution or opportunity space.

IV. Implications for Engineering Design Education

Educational approaches to teaching design thinking in traditional design disciplines (e.g., architecture, industrial design) have focused primarily on the learner's exposure to precedent exemplars—or ultimate particulars [29]— to build this repertoire [24]. The traditional studio educational experience pioneered in design education centuries ago follows this pattern, with an explicit focus on learning a relatively well-defined canon of examples [e.g., 32], but much of this experience has not been replicated in engineering, where design-centric practices are becoming increasingly common [10]. We posit that exposure to *Design Heuristics* can hasten, or even enable the learner's trajectory in such disciplines, where little formal canon or support for formalized repertoire currently exists. *Design Heuristics* scaffold the construction of conceptual repertoire by implicitly communicating the teleology and epistemology of design, as empirically derived from multiple examples. In this way, methods such as Design Heuristics that explicitly bridge precedent artifacts and form useful patterns of disciplinary knowledge are able to foreground intermediate-level knowledge in a way that scaffold students' understanding of design thinking.

Traditional design education is predicated on the knowledge of canon first, only allowing the implementation of variation later in the learning experience (e.g., copying successful designs before creating ones' own). We propose that introducing intermediate-level knowledge early in the learning process as externalized conceptual repertoire can scaffold the development of internal coherence. This scaffolding of students' design cognition in an educational context may progress as follows:

1. Instructors build students' knowledge of curated intermediate-level concepts (e.g., *Design Heuristics*) concomitantly with organic idea generation
2. Instructors and students relate intermediate-level concepts to the design artifacts (i.e., ultimate particulars) being generated
3. Students are then able to transfer the intermediate-level knowledge to a new concept in a different context
4. Over time, students begin to internalize the intermediate-level knowledge as a design pattern or guiding pattern of internal coherence, which functions as a cognitive schema, organizing past elements in the conceptual repertoire and preparing the repertoire for additional growth in the future (i.e., building a library of "design moves")

While many traditional design disciplines have built and maintained a canon of precedents taught as a form of acculturation into that discipline, many fields (e.g., engineering design) lack a widely accepted canon. These emergent design disciplines may lack documentation of precedent artifacts altogether, or exist as a discipline without established methods of curation of precedent artifacts that do exist. In these cases, heuristic generation, as we have demonstrated with *Design Heuristics*, serves both as a legitimation of precedent gathering practices—crucial for building a shared canon—and also supports the practice of inductive reasoning that occurs through the combination and classification of such artifacts.

V. Conclusion

We propose that *Design Heuristics* offer a conceptual bridge between design theories and the individual design precedents often provided to learners, forming a body of intermediate-level knowledge that is valuable in engineering design education and practice. We posit *Design Heuristics* as a collection of strategies that connect and build upon existing precedents, demonstrating generative value in the development of design ability and in the practice of design. This focus on the *content* of design thinking—what the designer is thinking *about* as they consider new concepts—is an important contribution to design theory, and represents a new way of conceiving the links designers form between precedent artifacts and their own conceptual repertoire.

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VII. Authors' biographies

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