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Innovative design thinking for breakthrough product development

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Abstract

Concept generation is the most critical task in breakthrough product development. This paper presents an Innovative Design Thinking (IDT) framework that models concept generation as a proposition-making activity according to the formation definition of logic propositions. IDT formalizes designers' verbal statements as either analytic or synthetic propositions through a cyclic operation of "specify-ideate-validate" at each abstraction level to generate a design concept which is logically feasible, functionally simple, and physically certain. Then, IDT guides designers through a zigzagging process which repeats the same cyclic operation at progressively less abstract levels to complete concept generation. Details of this cyclic operation and the zigzagging process are explained in this paper with an illustrative example presented.

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1. Introduction

Breakthrough products are developed by discovering unmet customer needs (CN), choosing exciting functional requirements (FR), ideating innovative concepts in terms of design parameters (DP), and finally optimizing design performance via process variables (PV) under constraints. Concept generation, where relationships between FR to DP are established, is the most important and challenging phase in breakthrough product development. It is important because the designer's creativity at this early phase will ultimately determine the product's quality at the later phase. It is challenging because, unlike analysis which evaluates existing options in a closed form, synthesis must create new concepts that never existed before. The reasoning activity of synthesizing multiple entities towards something new is very different from analyzing the performance of things in existing. The latter is well-supported by many modeling, simulation, and optimizing tools; whereas the former is poorly understood and ill-practiced largely based on the designer's experience [1]. This is the main hindrance of creative concept generation in design practice, which limits the success of breakthrough product development.

When designers brainstorm ideas at the beginning of product development, they typically express initial opinions and make preliminary suggestions using some verbal statements. Spoken language is the most common, and sometimes the only, mediator used by design teams during concept generation. Unfortunately, human language is inherently vague and often loosely expressed by people with different meanings and interpretations, making it difficult to use to generate, represent, and organize good design concepts. It is clear that, if these informal statements could be structured formally, such that their embedded meanings can be made explicit and evaluated objectively, then they will be more useful for developing breakthrough products. This is the motivation behind our Innovative Design Thinking (IDT) research to develop a framework that guides the designer to formulate their informal verbal statements as formal logic propositions to perform analysis and synthesis activities in new product development.

IDT organizes breakthrough product development into three consecutive stages: Functional Design (i.e., from CN to

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FR), Conceptual Design (i.e., from FR to DP), and Technical Design (i.e., from DP to PV). The Conceptual Design Stage is further divided as two iterative phases: the Concept Generation Phase and the Concept Improvement Phase. IDT treats concept generation as an organized "proposition-making" activity according to the formal definitions of proposition in logic [2-4]. As the designer proposes various DPs to satisfy the chosen FRs during the Concept Generation Phase, IDT guides the designer to organize his verbal statements as logic propositions (i.e., structured statements of subject-predicate pairs), so that various ideas proposed by different designers can be combined, compared, and selected systematically towards better design outcome. Based on logic definitions, two types of propositions are adopted in IDT: analytic and synthetic propositions. The logic orthogonality (or mutual exclusiveness) between analytic and synthetic propositions results in a two dimensional reasoning roadmap to guide IDT's Concept Generation Phase, which is carried out via three consecutive Steps. First, in the Formation Step, IDT guides the designer to make various analytic and synthetic propositions through a closed loop of "specify-ideate-validate" to form an initial option space which only consists of logically feasible concepts. Next, in the Organization Step, IDT adopts the Independence Axiom from the Axiomatic Design Theory (ADT) to classify those logically feasible concepts into uncoupled, decoupled, and coupled categories according to their degree of functional dependency [5-6]. Finally, in the Selection Step, IDT guides the designer to use various criteria to choose the best concept which is not only logically feasible and functionally simple but also physically certain. After completing these steps at a certain level, IDT then guides the designer to repeat the same steps at progressively more detailed levels until a tangible design concept is obtained or available design resources are exhausted.

From a practical viewpoint, IDT can be seen as a "hybrid" approach between the "decompose-generate-compose" cycle prescribed by the Analytical Target Cascading (ATC) [7-8], and the "layer-by-layer" zigzagging process suggested by the ADT [5-6]. As a result, IDT is most suitable for design practices in between the two extreme cases of analysis-based routine designs (by ATC) and synthesis-focused creative designs (by ADT). IDT can guide the designer to systematically alternate between analysis reasoning and synthesis reasoning to support a wide range of design tasks to achieve a good balance between creativity and practicality.

The focus of this paper is on IDT's Concept Generation Phase during the Conceptual Design Stage, specifically, the Concept Formation Step. Due to the space limitation, details of the Concept Organization and Selection Steps, which are similar to the process of applying the two design axioms prescribed in ADT, will not be elaborated in this paper. Interested readers are encouraged to study relevant ADT publications for a thorough understanding [9-10].

2. Theoretical underpinnings of IDT

Innovative Design Thinking (IDT) is not a single decision method based on certain fixed algorithms to optimize the design result; nor it is an exact design theory that imposes a normative view toward the design process. Rather, it is a domain-independent framework based on well-established definitions in logic, epistemology, and philosophical studies. It draws a set of relevant decision methods and design theories under a single framework to support early stage design. The six theoretical building-blocks of IDT are briefly summarized below.

(A) Reasoning: IDT models concept generation as a "proposition-making" activity based on the formal definition of proposition in logic. As designers propose different ideas of how to satisfy the targeted FR, IDT guides them to formulate their proposals as analytical and synthetic propositions, so that an initial space of logically feasible options can be formed for further comparison and evaluation.

(B) Representation: IDT represents a design concept as logic associations between a set of FR and DP entities, resulted from making analytic propositions within a hierarchy and making synthetic propositions across two separate hierarchies. Such a two dimensional representation scheme is similar to that of the Axiomatic Design Theory by Suh [5-6]. However, IDT uses the formal definition of logic propositions as its theoretical foundation to guide the ideation of design concepts, so that they can be better organized and compared systematically later [11].

(C) Operation: IDT prescribes a "specify-realize-validate" cycle as the basic operation at each abstraction level in order to form a space of logically feasible concepts. The cyclic IDT operation proposes "specified-by" and "realized-by" logic relationships, and then validates the proposed concepts with "part-of" and "means-of" logic relationships to complete the cycle of concept formation. The analytic-synthetic distinction together with the above closed-loop operation cycle enable IDT to systemically guide synthesis and analysis activities, which are often performed arbitrarily in current design practice [9].

(D) Complexity: Based on the assertion that design concepts with less functional complexity are more ideal [12-14], IDT employs the "functional dependency" property of proposed concepts, which can be revealed by different logic associations between FRs and DPs established from making synthetic propositions, to identify the functionally simple options. This notion of functional dependency in IDT is directly adopted from the Independence Axiom of Suh's Axiomatic Design Theory and Design Complexity Theory [12].

(E) Certainty: Among those logically feasible and functionally simple options, IDT further asserts that the best concept is the one with the highest estimated physical certainty. Accordingly, IDT suggests to use various estimation methods to rank-order and select the most physically certain concept. Many existing methods, such as Quality Function Deployment [15], the Information Axiom of the Axiomatic Design Theory [5], Analytic Hierarchical Process [16], etc., can be used to support concept selection based on probability estimation.

(F) Process: After completing the above cyclic operation of "specify-realize-validate" at a certain abstraction level, IDT follows a zigzagging pathway to repeat the same operation at progressively lowers abstraction layer to further evolve the