

A new model of conceptual design based on Scientific Ontology and intentionality theory.

Part I: The conceptual foundation



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This paper is devoted to developing an explicit and complete conceptual foundation for the establishment of a new conceptual design model. Based on Bunge's Scientific Ontology, it first clarifies some concepts (e.g., system, behavior, action) in the objective world. Based on the intentionality theory, a concept of need is then proposed as a concept in the intentional world. Thereafter, an explicit concept of function is elaborated as an intermediate concept between the intentional world and the objective world. Finally, another significant concept related to conceptual design, i.e., abstract principle, is also introduced as an intermediate concept. A detailed discussion demonstrates that the conceptual foundation developed here is more explicit and more complete than those in existing design models.

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Conceptual design is often regarded as a process that transforms a customer need or a desired function into a solution concept. It is widely acknowledged that conceptual design can largely determine the novelty, performance and cost of a technical product (Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002). Therefore, many design researchers have been interested in developing various systematic approaches or software tools to support conceptual design. Behind these approaches and tools, many conceptual design models have been proposed as their theoretical foundations, e.g., the Pahl & Beitz model (Pahl & Beitz, 1996), the Function-Behavior-Structure (abbreviated as 'FBS' later) models (Gero, 1990; Gero & Kannengiesser, 2004), the zigzag mapping model (Suh, 2001), and the Function-Behavior-State model (Umeda, Ishii, Yoshioka, Shimomura, & Tomiyama, 1996). Although the existing models of conceptual design have significant merits, they are still premature and have some significant issues that must be addressed.

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According to the research in philosophy of design (e.g. Galle, 2008; Love, 2000), one major issue is that 'there exists an unnecessary multiplicity of design concepts', which are unnecessarily confused and ambiguous. For example,



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Pahl and Beitz (1996) employs three primary concepts (i.e., function, physical effect and principle solution) to elaborate a conceptual design process, while the primary concepts in the FBS model (Gero, 1990) are function, behavior and structure; meanwhile, it is found that even the same term *function* in these two conceptual design models does not share the same meaning (Chen, Zhang, Liu, & Xie, 2013; Vermaas, 2013). Another major issue, as firstly noticed by Kroes (2002), is that existing models of conceptual design lack a logically coherent process that can elaborate how a concept in the intentional world can be gradually transformed into a concept in the physical (i.e., objective) world. There are also some other issues that cannot be mentioned here for conciseness.

Therefore, it is necessary to develop a conceptually explicit and logically coherent model of conceptual design. Such a new model of conceptual design cannot only allow lecturers of engineering design courses to teach their students explicit and logical knowledge about conceptual design, but also can help design researchers improve their understandings about the conceptual design process, based on which, it is then possible for them to develop more effective approaches or software tools to support conceptual design practices. In addition, such a new design model can also serve as a solid theoretical foundation for the design science research, which is aimed at developing reasonable theories and models of design, so that designers can utilize such theories and models together with the scientific knowledge to generate better design results (Cross, 2001).

Therefore, our research has been devoted to the development of such a new model of conceptual design. Our research work will be reported in two separate papers. In this paper, we attempt to develop a more explicit and more complete set of concepts for conceptual design research, which is expected to serve as the conceptual foundation of our new conceptual design model. In an accompanying paper that will come in a later issue of this journal, we will attempt to develop a logically coherent process model of conceptual design. Since conceptual design is now widely acknowledged as a process evolving from the intentional world into the objective world (Galle, 2009; Kroes, 2002; Vermaas & Dorst, 2007), this paper will employ a philosophical theory of intentionality (Jacob, 2010) and the Scientific Ontology (Bunge, 1977, 1979) to develop an explicit conceptual foundation for the conceptual design research.

This paper is organized as follows. Section 1 will employ the Scientific Ontology to clarify some basic concepts in the objective world (e.g., thing, system, behavior, state, action) related to conceptual design. Then in Section 2, a philosophical theory of intentionality (called *intentionality theory* later) will be used to propose a concept of (design) need in the intentional world. Thereafter, two intermediate concepts between the intentional world and the objective

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