

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

Part II: The process model

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To address the logical incoherence issue related to existing design models, this paper employs the conceptual foundation developed before to establish a new process model of conceptual design, i.e., the Need-Function-Principle-System model, which elaborates a conceptual design process with five major stages, i.e., clarification, synthesis, embodiment, analysis and prediction. The new process model can explain how a need in the intentional world is transformed into a function and then into an abstract principle in the semi-objective world, and finally into a model system in the objective world. The conceptual design of a hair-drying system is employed to demonstrate the developed design model. A discussion demonstrates that our process model of conceptual design is more logically coherent than existing design models.

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As mentioned in the preceding paper (Chen, Zhang, Xie, & Zhao, 2015), it is significant for engineering design community to have a conceptually explicit and logically coherent model of conceptual design, since it can not only allow design lecturers to teach students explicit knowledge about conceptual design, but also can help design researchers improve their understandings about conceptual design, which can further serve as a theoretical foundation for the development of effective approaches or software tools for supporting conceptual design practices. Nevertheless, since the existing models of conceptual design (e.g., Gero, 1990; Pahl & Beitz, 1996; Suh, 2001; Umeda et al., 1996) rely too much on intuition and experience, they are still ambiguous and fragmented. Therefore, our research has been devoted to developing a conceptually explicit and logically coherent model of conceptual design.

To address the logical incoherence and incompleteness of current conceptual design models, we propose a new model of conceptual design, i.e., the Need-Function-Principle-System model. In a previous issue of Design Studies, we have reported the conceptual foundation of this model (Chen et al., 2015), which has been developed based on the Scientific Ontology (Bunge, 1977,

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1979) and an intentionality theory (Jacob, 2010). Based on this explicit conceptual foundation, the new design model will elaborate how a conceptual design process can transform a concept (i.e., need) in the intentional world into a concept (i.e., solution) in the objective world (Kroes, 2002; Vermaas & Dorst, 2007). Meanwhile, this paper will also attempt to address another basic issue related to conceptual design, i.e., how a conceptual design process can synthesize basic physical principles (also called first principles) together to generate a solution concept for a desired function. Note that the existing models of conceptual design, such as the FBS model by Gero (1990) and the functional decomposition model by Pahl and Beitz (1996), largely depend on past design experiences (rather than basic physical principles) to generate solution concepts, and, therefore, cannot address the above basic issue. According to Cross (2011), a basic strategy that expert designers use to achieve design innovation is to design with first principles. Therefore, the latter issue is also critical for the development of a design innovation model, which is indispensable for the development of a software tool for supporting design innovation.

This paper will be organized as follows. Section 1 will briefly introduce the conceptual foundation developed in the preceding paper. Thereafter, Section 2 will propose a new conceptual design model, i.e., the Need-Function-Principle-System (abbreviated as NFPS later) model, to illustrate how a (design) need in the intentional world is transformed into a model system (i.e., a solution concept) in the objective world via a function and an abstract principle in the semi-objective world. Section 3 will employ the conceptual design of a hair-drying system as an example to demonstrate the design process model developed in this paper, followed by a discussion in Section 4. Finally, Section 5 concludes this paper.

1 An introduction to the conceptual foundation

Before elaborating the new process model of conceptual design, it is necessary to give a brief introduction to the conceptual foundation developed in the preceding paper (Chen et al., 2015), so that it is convenient for the readers to understand our work presented here. Table 1 is a summary of the primary concepts and their definitions developed before.

Note that the concepts in Table 1 are in different worlds, whose definitions are given in Table 2. Firstly, the concepts of thing, system, structure, state, behavior and action are in the physical world. Secondly, the concept of (design) need is in the intentional world, which is a world composed of the mental representations of both abstract objects and physical objects in human mind. Finally, the concepts of function, (abstract) principle, action class, and behavior class are in the intermediate world between the physical world and the intentional world. In addition, it should be noted that a conceptual design process usually cannot deal with the objects in

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