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On some unique features of C–K theory of design

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ABSTRACT

Concept–Knowledge theory (C–K theory) of design is a relatively new theory for describing reasoning and creative processes in engineering design. This paper describes some unique features of this theory. In particular, it is shown that C–K theory encompasses logical inferences that are more complex than classical abduction. A design process in C–K theory is rather motivation-driven and this motivation can be quantified by the concept called information content (entropy) measured under epistemic uncertainty. Since the Internet-driven information will play a major role in performing engineering design (building concept, acquiring domain knowledge, and alike) in the near future, the scope and limitation of building a C–K map by using the Internet is described. This provides some unexplored issues of engineering design.

1. Introduction

To describe reasoning and processes of innovation and creativity in engineering design, mapping of objects from one domain (or space) to another have been found effective. For example, consider the mappings (i) among Functions (F), Behaviors (B), and Structures (S) introduced by Gero [7], (ii) between Functional Requirements (FR) and Design Parameters (DP) introduced by Suh [21], and (iii) between Concept (C) and Knowledge (K) introduced by Hatchuel and Weil [8,9]. This article deals with some unique features of C–K mapping underlying the design theory called Concept–Knowledge theory (hereinafter referred to as C–K theory) [8,9]. A schematic illustration of C–K theory is shown in Fig. 1. As seen from Fig. 1, there are two interdependent domains called Concept Domain and Knowledge Domain in C–K theory of design. In addition, there are mappings between C and K, i.e., C → K, K → C, C → C, and K → K. This mapping is somewhat different compared to those in other design theories. For example, in Axiomatic Design [21] the mapping is allowed in a hierarchical manner: FR → DP → FR (new) → DP (new). The mapping FR to FR or DP to DP is not allowed in Axiomatic Design. However, one of the most remarkable features of C–K mapping is its ability to dealing with a *creative* concept—a concept that is undecided with respect to the existing knowledge at the point of time when it (the concept) is conceived. If such an undecided concept is pursued further, new knowledge might evolve in favor of the concept. As a result, both knowledge evolved and concept conceived become the part of design. Such a remarkable feature of C–K theory (i.e., an ability to deal with undecided concepts and co-creation of new knowledge) has been a subject of research. Some of the relevant works are described below.

Kazakci and Tsoukias [11] showed how to develop design tools for practicing creativity by using C–K theory. They have introduced a domain called Environment in addition to the domains of Concept and Knowledge to achieve this. Hatchuel and Weil [9] have shown that stability of object in Knowledge domain explains the topological structure of design modeling introduced by Braha and Reich [2]. Therefore, topological structure of design modeling and C–K theory are synergistic to each other in dealing with the structured knowledge for designing creative artifacts. Galle (2009) [32] has found that Function–Behavior–Structure models [7] avoid "as-yet non-existent" objects manifesting a phenomenon called un-embodied structure. To fill this gap, the idea of undecided concept of C–K theory can be used (Galle 2009, [32] pp. 335–336). Reich et al. [17] have critically analyzed the Advanced Systematic Inventive Thinking (ASIT) (a derivative of the Altshuller's Theory of Innovative Problem Solving [1]) and have shown that C–K theory subsumes innovation mechanism of ASIT. Hatchuel et al. (2011) [10] have shown that C–K theory helps overcome "fixation effects"—the effects that hinder creativity. They have found that the outcomes of C–K theory based design curriculum are measurable—a desirable characteristic for educating students with the ability of creative thinking.

There are other unique features of C–K theory that need investigations. For example, a question may be asked: Is it possible to position C–K theory in terms of abduction (an important logical inference for formally incorporating creativity (at least innovation))? In addition, since a concept is an undecided entity at the beginning, there must a "motivation" behind pursing it further. This raises a question: What is the nature of motivation involved in pursuing an undecided concept? Moreover, questions may be

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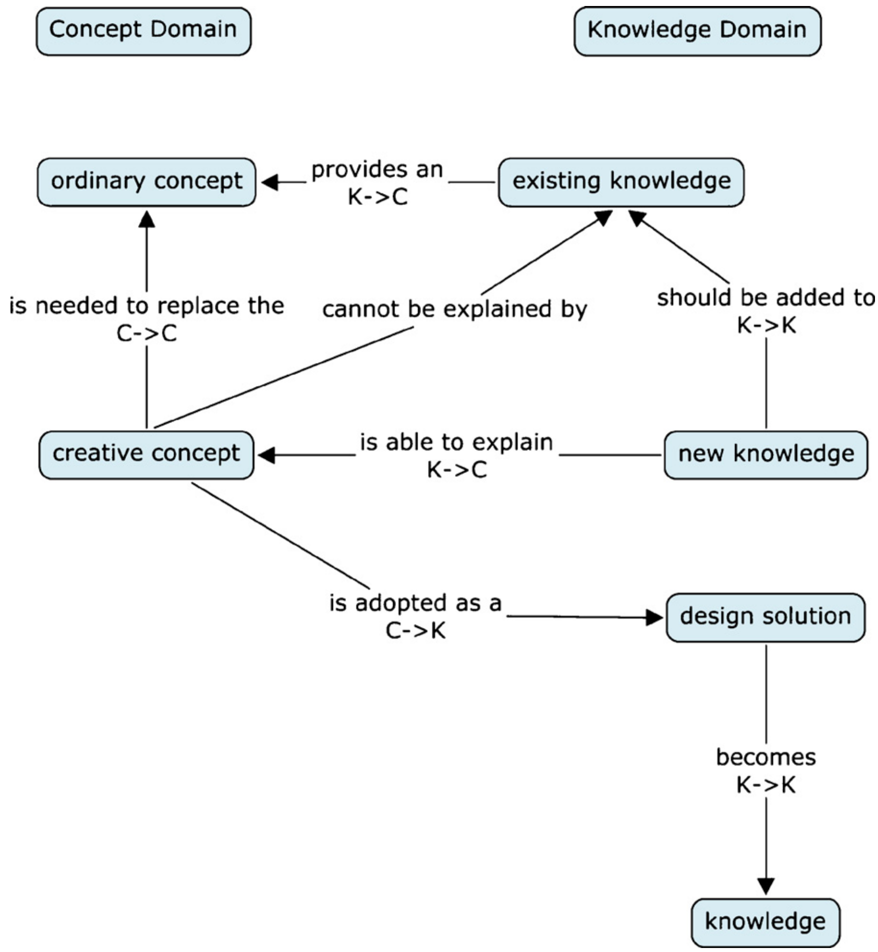

Fig. 1. An illustration of C–K theory of design.

asked: Is it possible to measure the information content (or entropy) of a concept even though it is undecided (i.e., under epistemic uncertainty)? How does the information content vary while continuing a design process in accordance with C–K theory? Is it possible to build a C–K map by using Internet-driven information resources?

The remainder of this paper provides answers to the above mentioned questions. The sections are organized, as follows: Section 2 describes C–K theory in terms of abduction and motivation. Section 3 measures the information content of creative and ordinary concepts from the view point of epistemic uncertainty. Section 4 provides a discussion on the findings in Sections 2 and 3 and highlights the implication of building C–K map using Internet-driven information under current information retrieval technology. Section 5 concludes this study.

2. Abduction, motivation and C–K theory

2.1. Abduction

Providing a logical explanation of a cognitive process of design has been an active area of research. Many authors have studied this issue using different approaches. For example, see the works of Yoshikawa [29], Zeng and Cheng [30], Kazakci et al. [12], Tomiyama et al. [23], and Ullah [26]. Some of the authors have identified that the logical inferences, namely, deduction, induction, and abduction, are associated with the cognitive processes of design. Particularly, abduction (opposite to deduction) is considered an important ingredient for dealing with the creativity (at least innovation) while continuing a design process [29,23,26]. There are many forms of abduction [26,18]. One of the basic forms is as follows:

$$\begin{array}{l} p \rightarrow q \\ q \\ \hline p \quad (\textit{a possible outcome}) \end{array} \tag{1}$$

The expression in (1) means that if the consequent (q) of a logical implication "$p \rightarrow q$" is true, then the antecedent (p) is a "possible" outcome. In other words, there might be other possible outcomes in addition to p. Thus, abduction refers to multiple outcomes. This is schematically illustrated in Fig. 2 using a logical implication "bird → fly."

A seen from Fig. 2, from the logical implication "bird → fly," "bird" and "some other objects" are the outcomes when "fly" is the requirement. If someone consults the knowledge of objects able to fly, he/she could find that an object called "helicopter" (for example) is consistent with the knowledge. Thus, instead of the solution called "bird," another solution called "helicopter" might be adopted as a design solution (an object that can fly), if it appears to be more appropriate for a given situation. A more human-friendly representation of abduction-based design process (Fig. 2) is illustrated in Fig. 3. The illustration in Fig. 3 is actually a concept map.[1] Thus, this concept map in Fig. 3 is a visual representation of

[1] Concept maps are graphical representation of entities and their relationships. Using concept map one can create a "meaning base" of an issue. The authors use concept maps throughout this paper to illustrate C–K map and other related processes. To know the details of concept map and its computing tools, refer to refs. [15,3,14].