Exploring problem decomposition in conceptual design among novice designers

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Conceptual product design is commonly described as problem solving. In the present study we attempt to expand this view. Focusing on the solution search phase, we analyse explicit and implicit problem decomposition techniques and integrate them into a descriptive cognitive model. To evaluate the prevalence of decomposition modes empirically, we provide results from a verbal protocol analysis study involving 16 senior students of mechanical engineering. Data indicated that the subjects apply top–down control strategies coupled to implicit decomposition. Explicit decomposition was used seldom and without obvious benefits. We relate these results to the model that considers implicit decomposition as an integral part of the problem interpretation process and discuss the role of decomposition in a structured idea generation process.

Keywords: design cognition, cognitive strategies, conceptual design, problem decomposition, protocol analysis

Divide et impera is the rationale of problem decomposition, one of the most essential problem-solving techniques in the psychological literature (Newell and Simon, 1972; Anderson, 1983). Decomposition has found its way to models of decision making (Gettys et al., 1987) and penetrated several normative theories of the design process, for example in mechanical (Pahl and Beitz, 1984) and software engineering (Horning and Randell, 1973; Sommerville, 2001). The pattern language (Alexander et al., 1977) is an example of a decomposition-based methodology from architecture.

Despite the emphasis that design domains place on problem decomposition, its psychological underpinnings have not been a topic of extensive research. The benefits of applying decomposition have been studied mostly in quite generic, non-design contexts (Dennis et al., 1996, 1999; Coskun et al., 2000). In design, the most recent, dedicated investigation of decomposition was carried out by

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Ho (2001) who identified two modes of decomposition, implicit and explicit. Explicit decomposition referred to the deliberate analysis of a function structure at the beginning of the design process. This corresponds to a typical textbook description of the method. In implicit decomposition, the function structure was not openly sought or revealed. However, an analysis of the design process demonstrated the existence of the structure, indicating that the problem had been decomposed implicitly. In this paper we call this proposition the dual-mode view of decomposition.

This paper examines problem decomposition in the solution search phase of conceptual product design, particularly related to the design of physical products. During solution search designers generate and evaluate concept candidates, making this stage crucial in determining the final product (Ulrich and Eppinger, 2003). Idea generation (IG) is a promising area for investigating problem decomposition, as it is a phase where repeated synthesis–analysis cycles are assumed to take place. The method we apply is verbal protocol analysis (Ericsson and Simon, 1984), which has been demonstrated effective for IG research (see Cross et al., 1996).

Our study of decomposition starts with a review of related theoretical and empirical work. This analysis leads to the formulation of a descriptive, cognitive model of design IG in product design, which treats problem decomposition as a specific problem-solving technique. In particular, we propose that explicit decomposition is a tool for verifying the usually spontaneously created initial implicit decomposition of the problem and that implicit decomposition is an inextricable part of the problem interpretation phase. Using two novice designer groups and two IG design tasks, we study empirically how the dual-mode view of decomposition is manifested in design IG.

The results showed that the designers mainly relied on implicit decomposition and the explicit decomposition was not essential for the designers, in an obvious contradiction to the educational design literature. Explicit decomposition was also clearly unrelated to structured control strategies that were constantly used in IG. Additionally we discovered that the designers were very solution-centred, but capable of constantly evaluating and discarding their ideas, even if instructed otherwise.

1 Design cognition

The current investigation approaches decomposition from the perspective of design cognition (Eastman, 2001). This paradigm describes design as information processing, employing explanatory concepts such as problem spaces, goal hierarchies, control strategies, and search methods (Akin, 1986; Chandrasekaran, 1990). In this framework, design is considered as ill-structured problem solving (Simon, 1973) because design problems define the problem in a fuzzy manner, with regards to initial state, goal state, and operators. This leads to