# *Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function–behaviour–structure coding scheme*

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*This study compares the design processes of designers in both digital and traditional sketching environments, where the digital environment emulates the traditional face-to-face, pen-and-paper environment. The design processes were empirically examined through protocol analysis using a coding scheme based on the function–behaviour–structure ontology. The distributions of the different types of segments, and their transitions in the two environments were quantitatively compared using Chi-Square tests and Paired-T tests. The results indicate that the design processes in the two environments were not statistically different in terms of their distributions and transitions. The higher-level cognitive activities were not affected by the change of medium. Some implications for design computing and design practice are discussed.*
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Conceptual design is perhaps the most crucial phase in the design development cycle. During this phase, designers set up the direction for the following design process, incubate creativity, and embody most of the values into design artefacts. Relatively unstructured and ambiguous sketches are created during this process. Designers often place great emphasis on these sketches, because they are thought to be associated with creativity (Herbert, 1988). In terms of human cognition, sketches promote the dialectical process between a sufficiently specified and coherent physical form, and abstract, conceptual, propositional knowledge (Goldschmidt, 1991, 1994). The use of

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sketches produces benefits not only as an aid to memory, but also in perceiving visuo-spatial relationships and reasoning about functional issues and goal-setting (Suwa & Tversky, 1996). Sketches are representations of the results of thinking process, decreasing the cognitive load of designers, and they are also involved in provoking creativity during designing (Suwa, Purcell, & Gero, 1998). In design cognition research, considerable effort has been focused on the roles of free-hand sketches in the conceptual design process and their relationship to designers' cognition (Purcell & Gero, 1998). Free-hand sketches are especially important to designers in the conceptual design process for sketches constitute a particular form of symbolic system characterised by syntactic and semantic denseness and by ambiguity that potentially can be used to generate more lateral transformations for design creativity (Goel, 1995). Syntactic disjointness and differentiation increase the syntactic denseness; for example, a system where each drawing belongs to not only one symbol type and is not clearly differentiated from other drawings has more syntactic denseness. Similar, semantic disjointness and differentiation increase the semantic denseness, for example, a system where the drawings and their referents are not fixed has more semantic denseness. Ambiguity of a system indicates the relationship amongst symbols, drawing and referents are not unchangeable (Goel, 1992). These features of sketches allow new ways of seeing and reinterpreting sketches that could provide new forms and abstract concepts. The convenience and speed of using sketches enable designers to generate and represent ideas easily and quickly.

In design computing research, establishing a computer-aided conceptual design (CACD) system has been an important topic (Dijk, 1995). The disadvantages of the current state of CACD indicate that few digital tools exist to address the early phase of the conceptual design, where fuzzy customer requirements are mapped to function specification and ideas are developed (Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002). Some regard computer-aided design as an inappropriate means for conceptualization (Lawson & Loke, 1997; Purcell & Gero, 1998; Verstijnen, Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998). This situation may result from the abilities of most current computer-based drawing systems. They are often non-dense and unambiguous in representations that potentially impede transformations, which play an important role in the conceptual design process. However, the computer has emerged as an ideation tool across design domains (Jonson, 2005). Some studies have compared the process of preliminarily computer-aided sketching to the process of free-hand sketching (Bilda & Demirkan, 2003; Plimmer & Apperley, 2002). Currently, a dense and ambiguous representation for CACD is still difficult. To solve this problem, other research has proposed proof-of-concept CACD systems that provide support for different cognitive activities involved in the conceptual design process. In this category, many promising CACD systems have been prototyped to

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