The impact of 3D CAD interfaces on user ideation: A comparative analysis using SketchUp and Silhouette Modeler

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It has been known for decades that CAD is unsuitable in conceptual design and many studies on CAD for ideation have focused on comparing design outcomes against those of manual sketching. Based on the notion that different CAD interfaces can have distinctive effects on ideation, novice designers performed sketch-3D modeling-resketch tasks using SketchUp and Silhouette Modeler. We found that the characteristics of 3D shapes are attributable to the geometric operations afforded by mathematical representations, and that participants not only adapted the visual appearance, but also annotated process-related information. To minimize the contraction of creativity, we recommend that CAD use multiple but compatible mathematical representations and be introduced in stages after users understand the relationship between visual forms and design values.

Keywords: design tools, computer-aided design, conceptual design, 3D modeling interface

Since the invention of interactive sketching systems (Sutherland, 1963) and subsequent advances in microprocessors and graphical user interfaces (Edwards, 2008; Moggridge, 2007; Shneiderman, 1983), the power of computer-aided design (CAD) has influenced the tradition of design practice in numerous ways. Accurate and scalable digital information replaced error-prone manual drafting (Weisberg, 2008, chap. 2), 3D modeling and realistic rendering allowed visualizing imaginary ideas (Cook & Agah, 2009), and scientific as well as physical simulation enhanced the performance and manufacturability of proposed designs (Sass, 2006).

Observing the potential of CAD in design practice, one of the primary goals of design research was to suggest the desired and effective use of CAD during the ideation stage. Schon and Wiggins (1992) and, subsequently Suwa and Tversky (1997), suggested that CAD assist the designer's perception and reflection for the discovery of new features. Prats, Lim, Jowers, Garner, and Chase (2009) contributed to the vision by proposing a feature that detects sub-shapes from the sketches. In subsequent efforts to assess its potential as a replacement for manual sketching, CAD was found to be inferior as an I/O interface

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(Ibrahim & Rahimian, 2010) and form synthesizer (Alcaide-Marzal, Diego-Mas, Asensio-Cusesta, & Piqueras-Fiszman, 2013; Stones & Cassidy, 2007). Several studies therefore recommended alternative roles such as a conversational interface (Lawson & Loke, 1997) or an information organizer (Meniru, Rivard, & Bedard, 2003). As CAD became more and more integral to the conceptual design process as a unique means of verbal–visual interaction (Johnson, 2005) or representations for conceptual, informative, and presentation purposes (Salman & Laing, 2014), Oxman (2006) and Kalay (2006) argued that digital media is bringing a new generation of the design profession and methodology beyond the support of traditional design practice.

Nevertheless, an indisputable result from CAD research is the superiority of paper sketching as a generator of diverse solutions. Goel (1995) reported that manual sketching produced a greater number of new solutions both syntactically and semantically than drafting-type symbol software. Bilda and Demirkan (2003) also showed that paper sketching has advantages in supporting feature perception, alternative solutions, and design problem conception. In a graphic design experiment (Stones & Cassidy, 2007) and similarly in a 3D modeling environment (Alcaide-Marzal et al., 2013), CAD tools generated a smaller number of total as well as unique solutions. In one exception, when compared against polystyrene modeling, 3D CAD facilitated novel solutions by reducing the burden for applying physical effects and undoing design experiments (Wojtczuk & Bonnardel, 2011).

While these academic efforts provided good insights on what *types* of advantages paper sketching has over CAD – diversity of outcomes, intuitive interaction, absence of selection effects, and support for quick experiments – what is less clear are the *relative* impacts of various CAD modeling interfaces implemented in different CAD systems (Alcaide-Marzal et al., 2013). We can attribute the lack of such an investigation to the tendency to view CAD as a single entity with invariable characteristics. This trend not only obscured the distinctive impacts of different CAD software, but also led to theoretical generalizations susceptible to change in the face of technological advances. Recent studies on 3D domains identified benefits of CAD that had been considered exclusive to paper sketching (Alcaide-Marzal et al., 2013; Wojtczuk & Bonnardel, 2011). With an increasing range of choice for the 3D modeling interface (Cook & Agah, 2009), the question of the variable impacts of different CAD tools seems to deserve further academic study (Alcaide-Marzal et al., 2013).

The second question of our study is to enhance our understanding of how the experience of a design tool affects the designer's ideation – a so-called 'language-bound' problem in design and cognitive science research. Despite its importance and popularity, few design studies (Stones & Cassidy, 2007) have concentrated on this subject, particularly with respect to the research