CAD Tools and Creative Design, Grounds for Divorce or Match Made in Heaven?

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1. Introduction

From the humble hand sketch to CAD models and high fidelity pre-production prototypes, the designer must embody and represent design intentions using a variety of tools in an attempt to provide creative solutions to often ill-defined design problems(Rittel and Webber, 1973). For the industrial and engineering designer these representations of design ideas are employed with two objectives in mind. First, they provide a means to describe, explain and define design intentions to the many stakeholders involved in a process of new product development (ULRICH, 2003). Second, design representations are used by the designer to reflect upon and develop one's own design thinking towards emergent solution ideas (SCHON, 1983, CROSS, 2007).

Although the need to communicate has obvious implications for which design tools are used, when, where and how, here we set the former of these two objectives aside to concern ourselves with the later; a personal, reflective and situated design activity. Within this act of designing, we discuss the media of design representation and the role it plays in providing opportunities for creativity. That is, the specific question we respond to here is that of CAD's influence upon opportunities for creativity in the generation and development of design ideas. Can CAD truly be creative?

Perspective CAD drawing by LDS

Before moving to discuss CAD's role and possible influence upon creativity, we will first present some of the principles and concepts that serve to underpin knowledge and understanding of design practice more generally, and the use of design tools in support of the representation of design intent specifically.

Fortuitously for our present discussion, design research over the past thirty years provides us with some important insights into the act of designing and the kinds

of thinking it involves. We commence our discussion with a short summary of the key principles and concepts that serve to underpin an understanding of the nature of design and the act of designing. We then contexualise CAD's role and use within this conceptual framework and consider its influence upon creativity. We conclude by arguing against what we see as a circular and limiting narrative that focuses on the strengths and limitations of CAD as a tool for creativity. Instead we propose a re-orientation that emphasises the designer as tool user and their expertise, skill and judgment in choice and use of various CAD tools. We conclude with a call for more work on understanding design expertise and the implications skilled judgment has for tool use and creativity in design.

CAD concept model by Hyun Bin Kim

2. A Context for CAD Use

Arguably, the seminal work on the nature of design practice, and one that has been influential in providing a means to understand design activity and design thinking is Donald Schon's (SCHON, 1983) much referenced notion of design as reflection on/in action. Briefly, in an analysis of a protocol from the conversations of expert designers with their students, Schon (ibid) proposes the principle of design as a reflective activity. Taking this position deign activity is characterised by reflective actions looping between action and reflection to develop thinking and propose new ideas (Lawson, 2006). Within this process, the representation or embodiment of design intent is critically important. The designer must externalise design intentions (as sketches, drawings, notes and annotations) in order to reflect upon design ideas and develop their own thoughts (Visser, 2006).

Important in influencing the nature of reflective action is the distinct character of the design problem (Rittel and Webber, 1973, Dorst, 1996). Design problems, unlike problems in the sciences, can be described as ill-defined or wicked. The defining feature of these ill-defined problems is that there is and cannot be one correct solution to the original problem, but many possible outcomes. In fact there may potentially be an infinite number of possible solutions and a limitless number of ways to proceed towards a final solution idea (CROSS, 2007). Nelson an Solterman (NELSON and STOLTERMAN, 2012) describe this engagement with the design problem as a search for an ultimate particular. The designer or design engineer must come to a solution to ill-defined problems that is itself new or particular to any other solution that may have come before. In doing, the solution should provide the best or ultimate possible result given the designer's emergent understanding of the design problem.

In order to progress towards the ultimate particular or best solution, the practitioner must first move to engage or frame the design problem (GOLDSCHMIDT, 1997, CROSS, 2007). To support this process of problem framing, the designer will deploy many tools and strategies as well as his own skills and knowledge in

an attempt to develop greater understanding. These may include information related to the nature of the problem, user requirements, contexts, target markets, existing solutions, processes of manufacture, materials, costing models and calculations. The point here is that the designer or design engineer, in a situated activity of reflective practice, will draw upon a vast array of methods, strategies and personal skills in order to frame the ill-defined or ill-disciplined design problem (LAWSON and Dorst, 2009). This knowledge then works as a framework to support the representation of design intentions, often as sketches and drawings, sometimes as CAD geometry, models and prototypes; a variety of design representations used in the response to the design problem.

CAD concept model by Hyun Bin Kim

Design representation, as a means to support design thinking, has also attracted much attention in design research (BADKE-SCHAUB, 2004, BILDA, 2003, COYNE, 2002, GOEL, 1995, Goldschmidt and Porter, 2004, ROBERTSON and RADCLIFFE, 2009). The introduction of new tools and technologies such as CAD, CAM and RP (Rapid Prototyping) has added to this interest in the role representation plays in support of design activity, particularly at a conceptual stage of design development (TOVEY et al., 2003, Lawson, 2006, Alcaide-Marzal et al., 2013, Aldoy and Evans, 2011).

Render by Michael DiTullo

Design representation can be thought of as a process of externalizing design intentions in a physical form (Self et al., 2013). Here we use the term physical to describe any externalized representation (sketches and drawings, as well as three dimensional prototypes and CAD models). This process of externalization through the physical representation of design intentions is a critical component principle of Schon's (op cit) reflective design activity. This is because an important aspect of the concept of representation is the notion of construction (Visser, 2006). Construction, according to Vissor (ibid), describes a process of constructing one's own thoughts in parallel to the construction of design representations. That is, design representations and the designer's developing thoughts and understanding of the ill-defined design problem, are constructed concurrently. There is no representation without thought and no thought without representation. They are inex-

tricably linked and associated. If we take this position, the importance of the media through which representations are made is elevated as a candidate through which we may develop knowledge related to design practice.

Finally, new product development can be described as a process that moves between periods of divergent exploration and stages of convergent specification (Cross, 2008). In fact NPD may be described as a tension between exploration in the search for creative solution and a pragmatic requirement to provide an ultimate particular or specified design solution (CROSS, 2007).

This is of course a very brief summary of some of the key concepts and principles that have emerged to inform our understanding of design practice. Although limited in its depth of discussion, it server us here in providing a conceptual framework within which we may discuss CAD use and its relationship to creativity in a more informed mannor.

3. Conceptual Design and CAD

As mentioned above, design activity can be characterised by periods of iterative, divergent exploration followed and/or proceeded with phases of convergent specification (Cross, 2008). Conceptual design practice has often been associated with the former (GOEL, 1995, Jonson, 2005, Self et al., 2013). That is, during conceptual design, exploration and iteration appear to characterize design moves and the kinds of design representations made. In order to avoid fixation (PURCELL and GERO, 1999) and provide opportunities for creativity in the proposition of initial solution ideas, design representation requires a necessary ambiguity (BILDA, 2003). That is to say, in reflecting upon solution ideas the designer may interpret design representation in different ways in order to foster further exploration. A necessary ingredient of conceptual design and the kinds of design representations constructed to support it, is the principle of divergence. Goel (GOEL, 1995) terms this divergent approach the lateral transformation of design ideas. Lateral transformation may best be explained through its contrast to vertical transformation. During the lateral transformation of design intentions the designer or design engineer moves from one idea to another in an explorative process of representation, move and reflection on action.

In contrast, vertical transformation is characterised by movement from one solution idea to a more developed variation of the same idea. Goel's (ibid) notion of transformation has obvious parallels with design divergence/ convergence (Cross, 2008, ULRICH, 2003), with conceptual design often associated with a divergence and exploration that facilitates the generation of more creative design solutions(Jonson, 2002, ROBERTSON and RADCLIFFE, 2009). Ergo, if this divergence and explorative approach is disrupted by methods and tools that tend to constrain, exploration, divergence and interpretation in the generation of solution ideas may be at risk.

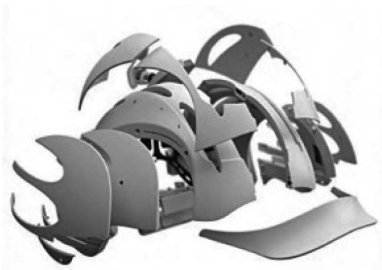
Design concepts, LDS, UK

Let us now turn to consider this hypothesis as a response to our original question of the implications CAD's use has for creativity, particularly during Conceptual design: Because of the convergent, explicit and vertical nature of CAD, it is less well suited as a tool of divergent exploration. As a result, its use will constrain exploration of design ideas and result in a final design solution that may be considered to be a less creative response to the original problem. However, below we argue against this position by highlighting the role of the designer as tool user and the expertise and judgment they potentially bring to tool choice and use.

4. CAD, the Curtailer of Creative Conceptual Design?

The use of CAD has often been criticized for its inability to easily allow lateral transformations, the more specific or fixed representations that CAD constructs and its inability to provide opportunities for iterative exploration (Lawson, 2006, DORTA, 2008, Fish, 2004, GOEL, 1995, Jonson, 2002).

Taken together, this appears to be a reasonable assumption. CAD, by its nature, is a process of vertical construction. Representations are built vertically. The designer appears to be constrained by the algorithmic nature of the CAD software, by its icon and tool based interface which appears to promote a more gradual construction. Design representations in CAD appear more certain and less open to interpretation.



Exploded drawing, LDS, UK

The argument goes thus: If the use of CAD tools constrains exploration of ill-defined design problems during conceptual design, this then has implications for the designer's ability to take a solution focused approach to problem framing, which may inhibit an ability to identify possible creative solution ideas. This is because exploration and iterative divergence appear critical in the identification of a best or ultimate design solution.

This all appears reasonable in principle and has been cited in existing work on the use of CAD as an influence upon design activity (Lawson, 2004, Lawson, 2006, TOVEY, 2000, ROBERTSON and RADCLIFFE, 2009, CROSS, 2007, GOEL, 1995, DORTA, 2008).

However, we feel such a tool-orientated view of the use of CAD and other design tools does not account well for the role and influence of the user; the *deign* practitioner. As a result, to focus upon the intrinsic character of CAD and its constraints on creativity fails to take account of the influence of the tool-user and their ability to engage and use tools in the generation and development of creative design solutions. After all, a tool is only a tool in-so-far as it is used as such (HEIDEGGER, 1962).

CAD's ability to support the vertical, detailed specification of design intentions is well established. What is in question is its ability to foster creative design solutions during a highly reflective conceptual design activity.

As previously stated, conceptual design practice can be described as a tension between divergent exploration and convergent specification(Cross, 2008). On the one hand, the designer or engineer needs to develop a clearer understanding of the ill-defined design problem. To do this, design representations are deployed, underpinned by the designer's own skills and expertise, in order to help frame the design problem through the proportion of solution ideas. These design intentions, embodied as design representations, provide opportunities for the identification and development of creative solutions. So, in order to facilitate opportunities to identify creative solution ideas during conceptual design, the kinds of representations made must facilitate interpretation and divergent exploration. However, as mentioned above, design activity is not only concerned with creative exploration and expression, design must also converge to specify a final or ultimate solution(NELSON and STOLTERMAN, 2012). In this sense both divergent exploration and convergent specification are required at every stage of design development. That is, during a reflective and conceptual phase of design activity, in the construction of representations, framing of the design problem and the proposition and development of solution ideas, the designer must both explore creative design solutions, but also consider their pragmatic application as final products and systems. One may come up with what appears to be the most creative and innovative solution. However, if the same solution fails the tests of usability, function and engineering, what may at first seemed to be a creative epiphany can quickly become a misguided pipe dream.

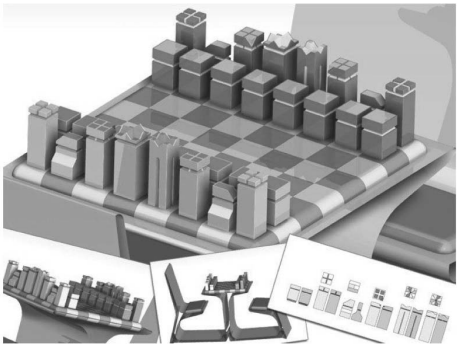
CAD concept rendering, LDS, UK

In this regard the successful use of CAD or any other design tool in the development of creative design solutions depends not so much on the inherent qualities of the tools themselves, but upon the designer's own skills, knowledge and judgment with regard to their use in support of the competing requirements of divergent exploration and convergent specification. Within this context, the tool itself, its affordances and limitations, are at the bequest of the tool user. Tools of design representation, CAD included, are deployed with informed skill, judgment and expertise. In this context the tool and its influence upon practice, quickly becomes inconsequential as the skills and judgment of the designer or design engineer take precedence. That is, the tool and any influence it may have upon the representation of design intent, is critically subject to the expert judgment of the skilled practitioner.

Design and design development after all is a process of compromise in the face of often limitless possibilities. Knowing when, where and how to deploy the right tool for the right job is part of what it means to be an expert.

5. CAD and Creativity, Why Ask?

If we re-orientate our focus towards the skills and expertise of the tool user, asking of CAD's influence upon creativity during conceptual design becomes something of a misnomer. That is, CAD has no influence upon creativity or anything else unless it is used as such by the designer or engineer.



CAD concept rendering, provided by Michael DiTullo

With a greater focus upon the influence of the tool user as use relates to a relationship between design tool, design representation and creativity, we may start to explore the ways in which expertise and judgment define both tool choice and use and the ability to develop creative solutions in the face of often ill-defined design problems.

For example, limited design expertise may result in a slavish dependence upon a particular CAD tool. More seasoned practitioners have an ability to make more informed judgments upon which tool to use, when, where and how (Self, 2012).

Under what conditions an ability to make more informed judgments about tool choice and use as design activity alternates between divergent exploration to convergent specification is still unclear. Here we do not attempt to address the question of the relationship between expert judgment, CAD use and creativity during conceptual design practice. Rather, we highlight the role of the tool-user. In doing, we argue for a more user-orientated evaluation of the ways in which CAD and other tools of design are deployed in the construction of design representations in response to ill-defined design problems. This re-orientation will move the discussion away from what we see as circular and limiting arguments centred on the strengths and limitations of individual tools. Instead we call for a more holistic interpretation of design tool use that sees the expertise and judgments of the user as central to any question of the tool's relationship with creativity.

Through this fresh perspective further work may be done on the role and influence expertise and judgment play during a reflective design activity. This work may then act as a foundation for educating design and engineering students in their use of CAD and other tools of design representation. This education must go beyond a prescriptive learning of tools and techniques to consider the rich context of tool use. The skills and expertise taught will then offer the best opportunities for both creative and pragmatic design solutions to emerge during the representation of design intent and exploration and development of design ideas.

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