The 2nd International Conference on Design Creativity (ICDC2012)

Glasgow, UK, 18th-20th September 2012

INFLUENCES OF DESIGN TOOLS ON CONCEPTS GENERATION

G.V. Annamalai Vasantha [1], A. Chakrabarti[2] and J. Corney[1]

[1]Design Manufacture and Engineering Management, University of Strathclyde, Glasgow, UK
[2]IDeaS Lab, Centre for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India

Abstract: Concept generation plays a vital role in establishing a broader foundation in the design process to create novel products. In globalized, collaborative, designing scenario, unambiguous representation of captured ideas to explicate designer's thoughts is important in sharing and reuse of concepts. Various design studies noted the impact of design tools on concept generation. However, the results did not detail the influences of variety of tools in representation and reinterpretation of concepts through captured design documents. This paper aims to understand the influences of conceptual design tools: Mobile e-Notes Taker™, Wacom™ Tablet, and Computer with Rhinoceros™ CAD on concept representation and reinterpretation, during original and redesign phases. Analyses of six individual designers' using video protocol studies conducted in original and redesign phases reveal that the design tools had significant impact on concept generation, in terms of the number of concepts generated and the textual and graphical representation of the design elements.

Keywords: *Concept generation, design tools, representation, reinterpretation*

1. Introduction

Innovation is a key factor to sustain in this competitive globalized industrial market. Designers are increasingly being stressed to create quality innovative products in faster cycles. Typically, designers are trained and motivated to be creative, where creativity is often expressed through fluency, flexibility and originality (Renzulli et al., 1974). A common definition of creativity proposes that "Creativity occurs through a process by which an agent uses its ability to generate ideas, solutions or products that are novel and valuable" (Sarkar and Chakrabarti, 2011). It has been shown that there is a positive correlation between the number of ideas produced during the design process and the novelty of the design concepts (Srinivasan and Chakrabarti, 2010). People, product, process, tools, organization and environment in which designing takes place (Blessing et al., 1995) have significant impact on the idea generation process. In these facets, design tools play a vital role in capturing

designers' thought processes and in facilitating sharing and reuse of design outcomes. Design tools assist 'reflective conversation' (Schön, 1983) between designers and design outcomes (e.g. external representations of requirements and solutions) which help generate a mental image that, in turn, may produce more sketches (ideas) which may, again, generate another mental image, and so on and so forth (Fish and Scrivener, 1990).

It is a designer's responsibility to choose appropriate design tools in the design process, based on understanding of the ability of each tool alternative available. However, studies have shown that although the frequency of use of CAD is less for immature designs (i.e. conceptual stage), it is still the most frequently used mode of working (Robertson and Radcliffe, 2009). They argue that a possible reason is the importance of digitalization of design outcomes, which is important for future analysis and process integration. Ibrahim and Paulson (2008) pointed that the transitional and iterative conceptual phase is a potential knowledge-loss period that is identified in the product development lifecycle process. But this raises the question as to whether designers really understand the influences design tools have on their creativity and outcomes generated. While Cham and Yang (2005) cited a number of good examples of successful integration of CAD and design education, this situation is hardly universal.

Various design studies have been conducted to understand the differences between pencil-and-paper-aided-designing and CAD designing, especially for their impact related to creativity in design. Most of the studies conclude that CAD is not suitable during the conceptual stage, as it exerts a negative influence on creative design and provides inadequate I/O systems to support intuitive idea creation (Whitefield, 1996; Kwon et al. 2003; Lawson, 2002; Stones & Cassidy, 2007). Geol (1995) found that levels of ambiguity were much higher in freehand sketching than in digital working. He concluded that sketching supported creativity in design more effectively than constrained computer usage did, particularly in terms of supporting reinterpretation. Alternatively, Won (2001) argues that the frequency of reinterpretation could be accounted for by the speed of digital working – the ability to 'move-see-move-see' that computers support so effectively. But he concluded that more alternatives could be generated using conventional drawing than using the computer.

Robertson et al. (2007) found that CAD enables enhanced visualization and communication, but with the negative effects of premature fixation, circumscribed thinking, and bounded ideation. They argued that enhanced visualization and circumscribed thinking cause students to develop a false sense of reality of CAD models. Lawson (1997) pointed out that certainty in the finished appearance of a digital mark proves destructive and restrictive in the early stages of design. Stones & Cassidy (2007) highlighted that CAD systems usually oblige designers to generate an early, precise, external representation of the object to be designed, and to use highly structured rules, which orients their reflections and does not correspond to their spontaneous process of creation.

Kwon et al. (2005) argue that the limitation of intuitive sketching capabilities in CAD tools is a reason for their inapplicability during the conceptual phase. Ibrahim and Rahimian (2010) illustrate that neither manual sketching tools nor CAD software are the better media for current conceptual design communications. They found that design semantic gets lost when manual design fails in articulating an explicit design idea, while design creativity diminishes when using arduous CAD software. Stones & Cassidy (2010) studied the impact of design tools (conventional paper-based sketches and digital tools) on reinterpretation during graphic design ideation activity. From their experimental results with student-designers, they have shown that paper-based sketches can support the vital process of reinterpretation that generates new ideas. Rosenman & Gero (1996) argue that a single-model

approach to representing a design object is insufficient for modelling the different views of the different disciplines.

It is clear from these literature results that for the conceptual stage, current CAD software is not yet a better alternative to replace conventional sketching tools, even though CAD provides enhanced visualization and speedy manipulation of objects. However, the importance of capture and reuse of digitalized design outcomes forces us to develop enhanced novel design tools that retain the merits of both the medium. For developing such tools, it is vital to understand current behaviour of designers in using various conceptual tools in terms of the textual and graphical representations of captured design documents. Also, behavioural changes of designers in reinterpretation of the captured design documents need to be studied across various conceptual tools. Literature does not report in any detail the behavioural changes of designers in representation of concepts in captured design documents. The focus of this paper is to understand the influences of conceptual design tools – Mobile e-Notes Taker™, Wacom™ Tablet, and Computer with Rhinoceros™ CAD – on concept representation and reinterpretation during original and redesign phases. In literature, reinterpretation is studied during original designing rather than in the redesigning phase. We intend to study the influences of original captured documents in redesign phase.

2. Research objectives and methodology

The aim of this paper is to study the impact of conceptual design tools on the behavioural changes of designers in (1) representation of design concepts in design documents captured during both original and redesign phases, and (2) reinterpretation of captured concepts during the redesign phase. A concept is defined as an entity that satisfies an overall function (Srinivasan & Chakrabarti, 2010). We have chosen Mobile e-Notes Taker™, Wacom™ Tablet, and Computer with Rhinoceros™ CAD (Figure 1) as an initial set of conceptual tools for this study. Mobile e-Notes Taker™ and Wacom™ Tablet were selected for their potential to replace pencil and paper tool which are currently the most commonly used aid for the conceptual design, and also on their ability to support capture and reuse in digitalized formats of design concepts. For comparison with CAD, Rhinoceros™ CAD was chosen because it has been widely used in our design centre (CPDM, IISc, Bangalore) as a conceptual CAD tool. Mobile e-Notes Taker™ is a portable handwriting capture device based on natural handwriting as input. A plain paper of any kind can be attached to the tool and the Hi-Tech's electronic pen can be used to capture, store and share handwritten drawings, sketches and notes. In this study we used Wacom™ DTU-710 tablet. The Wacom DTU-710 Interactive Pen display combines an LCD monitor with a Wacom tablet. This gives a direct point-and-draw-on-screen interface that can be used with a PC. Rhinoceros™ CAD that is widely used during conceptual designing. Rhino offers uninhibited free-form 3-D modelling, extreme precision, unrestricted editing, 2-D drafting, annotation, illustration, compatibility, and a short learning curve.

Figure 1. Mobile e-Notes Taker™, Wacom™ DTU-710 Tablet, Computer with Rhinoceros™ CAD

A map of the hypotheses explored in this work is shown in Figure 2. Representation of captured concepts, reinterpretation of captured concepts in the redesign phase, designer adaptability to design tool, time taken to capture each concept are the four parameters studied in detail. Representation of captured concepts is studied through textual and graphical formats. Textual contents are analysed by counting the number of words used to express function, behaviour and structure elements of the concepts; whereas graphical contents are analysed using the number of distinguishable components represented through sketches and diagrams. For distinguishing function, behaviour and structure elements, the definitions used by Chakrabarti et al., (2005) are used.

- *Function: Descriptions of what a system does: it is intentional and generally at a higher level of abstraction than behaviour.*
- *Behaviour: Descriptions of how a system does its function. This is generally at a lower level of abstraction than function.*
- *Structure: Structure is described by the elements and interfaces with which the system and its immediate interacting environment are constructed.*

Reinterpretation of captured concepts are analysed by the ambiguity and incompleteness of design elements and assumptions made by the designer working on redesign phase. Ambiguity can be defined as 'interpretable in two or more distinct ways' or as 'vague or imprecise' (Stacey and Eckert, 2003). Video protocols have been analysed to segment ambiguous portions expressed by each designer. Adaptability with the design tools has been studied through comfort of the designer. Video protocols and audio transcripts have been used to understand and segment portions of uncomfortable behaviours. Time taken to capture each concept is noted by using timestamps in the video protocols. We have formulated the following hypotheses to be verified in this study:

2. Conceptual design tools have a significant impact on the number of concepts generated.
3. Conceptual design tools have a significant impact on the amount of time spent by the designer in capturing each concept.
4. Conceptual design tools have a significant impact on the representation (graphical and textual format) of captured concepts in terms of functional, behavioural and structural elements.
5. The amount of time taken to capture each concept has a significant impact on the representation of captured concepts.
6. Formats of representation of captured concepts have a significant impact on the reinterpretation in the redesign phase.
7. Designer adaptability to a design tool has a significant impact on the representation and reinterpretation of captured concepts.

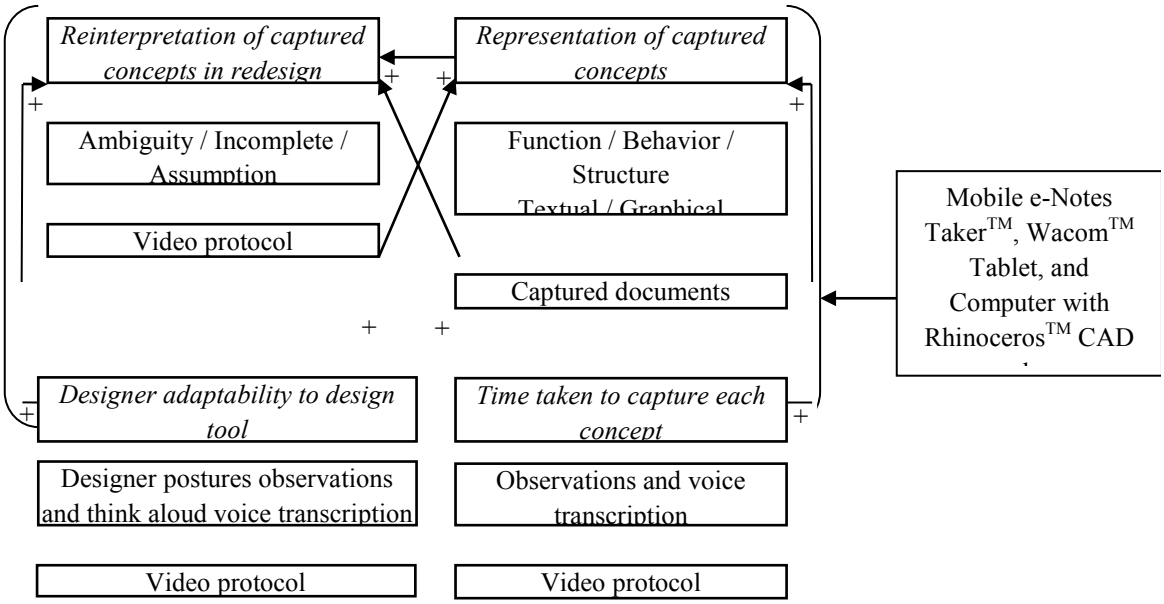

Figure 2. Research hypotheses map

To verify these hypotheses, in-house design experiments are conducted in a laboratory setting. Table 1 elaborates the structure of the design experiments conducted with the three design tools. To study the capture and reuse aspects, original and redesign experiments are conducted. Three original and three redesign experiments are conducted with four Master-of-Design students and two design researchers (Master-of-Design and Engineering). Industrial experience of the six designers varies from none to three years. A single design problem is used in all six experiments. For the redesign experiments, documents captured during the original experiments are provided as input. Only task clarification and conceptual design phases are covered in these experiments. Designers are given adequate training to use the tools before conducting the experiments. During the design experiments, each subject is asked to 'think aloud' such that the researcher can obtain a rich externalisation of their thoughts and activities from the experiments.

Table 1. Structure of design experiments and time taken for each experiment

Tools	**Original** (Design problem 1)	**Redesign** (Design problem 1)
Mobile e-Notes Taker™	Designer 1 – 1Hr 5Min	Designer 4 – 44Min
Wacom™ Tablet	Designer 2 – 34Min	Designer 5 – 25Min
Computer with Rhinoceros™ CAD	Designer 3 – 1Hr 33Min	Designer 6 – 1Hr 33Min

3. Results

8. Conceptual design tools have a significant impact on the number of concepts generated.

Table 2 details the number of concepts generated in the original and redesign experiments across the three design tools. Captured documents are analysed to note the number of captured concepts. A preliminary concept is defined as an idea to solve the given design problem; whereas a detailed concept is taken to one elaborated with more details. Designers using computer with Rhinoceros™ CAD have chosen MS PowerPoint to explore preliminary concepts, and used Rhinoceros™ CAD in

detailing the design. In the original design experiments, the number of concepts generated in Mobile e-Notes Taker™ and Wacom™ Tablet are higher compared to those using the CAD software. Reduction in the number of ideas, when Computer (MS PowerPoint) with Rhinoceros™ is used, could be due to premature fixation, as pointed out by Robertson et al. (2007). The level of precision necessary in articulating the concepts could be another reason for a resistance to change and develop newer concepts with Rhinoceros™ CAD. In the redesign experiments, the number of concepts generated does not seem to be impacted much by the tools. This could be due to fixation with the original concepts provided during the redesign phase. Overall, the results indicate that conceptual design tools have significant impact on the number of original design concepts generated.

Table 2. Number of concepts generated in the original and redesign experiments

Tools	**Original**		**Redesign**	
	Number of preliminary concepts	Number of detailed concepts	Number of preliminary concepts	Number of detailed concepts
Mobile e-Notes Taker™	7	5	2	1
Wacom™ Tablet	-	6	-	1
Computer (MS PowerPoint) with Rhinoceros™ CAD	2	1	1	1

9. Conceptual design tools have a significant impact on the amount of time spent by the designer in capturing each concept.

Table 3 elaborates the amount of time spent on capturing each preliminary and detailed concept, in three point estimates. Video protocols have been used to segment and record the time spent on capturing each concept. In Mobile e-Notes Taker™, the amount of time spent in capturing concepts vary more uniformly (standard deviation for capturing detailed concepts: 227 seconds) than in other tools. The fixation highlighted in the previous hypothesis in using Rhinoceros™ CAD is indicated by the amount of time spent on detailing concepts. Even though many concepts are generated in Wacom™ Tablet, the non-uniform time distribution in capturing concepts leads to stronger indication of occurrence of fixation. These indicate that conceptual design tools have a significant impact on the amount of time spent by the designer in capturing concepts.

Table 3. Amount of time spent on capturing concepts in original and redesign experiments

Tools	**Original**						**Redesign**					
'-' represents for one, two or no concepts generation	Time in capturing each preliminary concept (seconds)			Time in capturing each detailed concept (seconds)			Time in capturing each preliminary concept (seconds)			Time in capturing each detailed concept (seconds)		
	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max
Mobile e-Notes Taker™	8	27	55	280	403	720	103	-	267	-	-	117
Wacom™ Tablet	-	-	-	67	260	1064	-	-	-	-	-	630
Computer (MS PowerPoint) with Rhinoceros™ CAD	43	-	132	-	-	3200	-	-	182	-	-	2325

10. Conceptual design tools have a significant impact on the representation (graphical and textual format) of captured concepts in terms of functional, behavioural and structural elements.
11. The amount of time taken to capture each concept has a significant impact on the representation of captured concepts.

Table 4 shows the number of textual and graphical contents in terms of functional, behavioural and structural elements of captured concepts in the original and redesign experiments. Captured documents were analysed to segregate the number of words and distinguishable components used to represent the concepts. Observations from Table 4 are the following:

- Textual descriptions of concepts both in the original and the redesign phase are substantially higher in Mobile e-Notes Taker™ then other tools.
- Graphical elements are used to represent mostly the structural elements of concepts in all the tools. Except Wacom™ Tablet where functional elements are also graphical represented.
- Most behaviour elements are represented textually; that is higher in Mobile e-Notes Taker™.
- Since only few distinguishable structural components with precision are captured in Rhinoceros™ CAD, factors mentioned by Robertson et al. (2007) such as large amount of detail and interconnectedness and the complexity of the model influencing premature fixation might be questionable.
- Comparing Tables 3 and 4 reveals that only with Mobile e-Notes Taker™, the amount of time taken to capture each concept has impact on the wider representation (function, behaviour and structure elements) of captured concepts. In other tools, only precision in representation (especially structure elements) is increased with the amount of time spent.

The observations indicate that conceptual design tools have a significant impact on the representation of captured concepts. The amount of time taken to capture each concept does impact on the representation of captured concepts but in varying levels of precision and expression elements.

Table 4. Representation formats of captured preliminary and detailed concepts in original and redesign experiments

Tools	**Original**						**Redesign**					
	Textual			Graphical			Textual			Graphical		
	Fun.	Beh.	Str.	Fun.	Beh.	Str.	Fun.	Beh.	Str.	Fun.	Beh.	Str.
Mobile e-Notes Taker™	14	24	33	-	-	-	12	60	27	0	9	7
	33	150	92	0	8	36	0	28	8	0	0	0
Wacom™ Tablet	-	-	-	-	-	-	-	-	-	-	-	-
	-	3	-	25	1	23	21	1	9	4	-	12
Computer with Rhinoceros™	4	7	27	-	-	-	-	13	42	-	-	-
	-	-	-	-	-	4	-	-	-	-	-	9

12. Formats of representation of captured concepts have a significant impact on the reinterpretation in the redesign phase.

Table 5 shows that the amount of time spent by the designer in reinterpretation of original concepts is very minimal in the redesign experiments. Textual or graphical format does not significantly change the reinterpretation time. Video protocols show that the designers were interested to understand only the overall working principle of the concepts, rather than looking into the details of the concepts. Also, only the concept chosen by the original designer was focused on during the redesign phase. This could be one reason for the small number of redesign concepts generated. Goldsschmidt (1994) statement 'one read off the sketch more information than was invested in its making' could be valid for original designer rather than designer using original captured documents in redesign. Some observations relevant for the reinterpretation hypothesis are:

- In Rhinoceros™ CAD and Wacom™ Tablet, deleted and erased contents were not captured and subsequently not provided in the redesign experiment.
- The designers involved in the redesign phases assumed the original designer's thoughts and progressed accordingly.
- The designers found difficulty in Rhinoceros™ CAD to link the design problems and the requirements generated by the original designers.

Table 5. Time spent on reinterpretation of captured concepts in the redesign experiments

Tools	Amount of time spent on reinterpretation of all the original concepts (seconds)
Mobile e-Notes Taker™	310
Wacom™ Tablet with viewing facility	128
Computer (MS PowerPoint) with Rhinoceros™ CAD	309

H6. Designer adaptability to a design tool has a significant impact on the representation and reinterpretation of captured concepts.

Video protocols are analysed to understand a designer's discomfort during interaction with the design tools. Before and during the experiments, none of the designers questioned the ability and usability of the given design tools. Except for few adjustments, all designers were well adapted to the conceptual design tools. The few minor adjustments carried out by the designers were: observing the right mode of capture function, body movements to orient themselves for using the tool, paper adjustments, mouse requirement, tool orientation, transferring between paper sheets and continuation of capturing, and modification being restricted by the original designer. Bonnardel and Zenasni (2010) argue that technology developments should be adapted to designers' cognitive processes instead of requiring them to adapt to new technologies. However, considering the highly adaptable nature of the designers, it is difficult to find real cognitive, technological needs of the designers. Adaptability is not found to be an issue with the assessed tools. All the results obtained for hypotheses H1-H5 are not influenced by adaptability.

4. Discussion and conclusions

Figure 3 summarizes the findings in the influence diagram from the experiments analyses. The foremost implication from these results is to help designers understand and learn the facilities provided

by design tools and their influences on the design process. From the industrial perspective, efficacy of design tools in capturing and reusing concepts in appropriate representation for better reinterpretation during the redesign process needs to be established

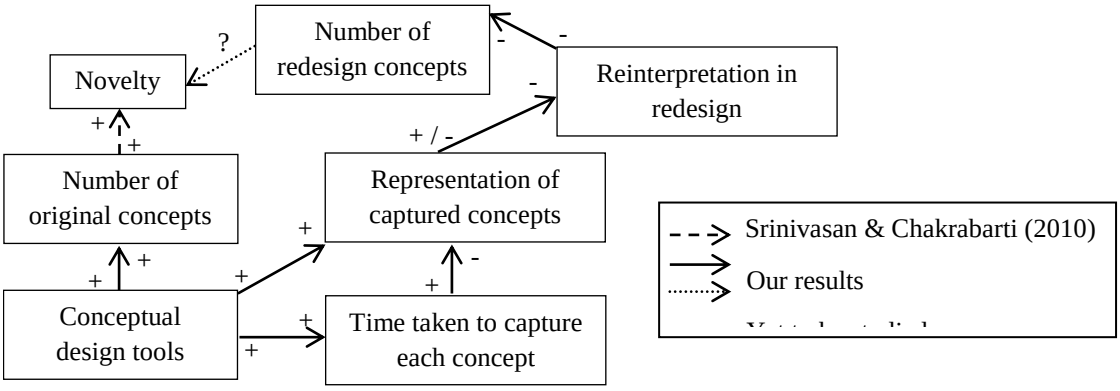

Figure 3. Influence diagram from the research findings

Since less time spent in reinterpretation process could have strongly influenced the number of redesign concepts generated, designers have to be trained in the reinterpretation design process to extract necessary knowledge from the concepts originally captured, rather than assuming about the original designer's thoughts process. Also, design tools need to aid the reinterpretation process because none of the tools currently support capture of all necessary information and knowledge required for the redesign process. Notable proposals such as representation of the functional properties of design objects to accommodate multiple views of design objects in a collaborative CAD environment (Roseman and Gero, 1996) and agent models (Maher et al. 2007) to monitor and augment designer in capturing and reusing required information and knowledge need to explored for supporting conceptual paper-based and CAD tools. But to build effective agent models to support reinterpretation, the core descriptive research question to be answered is 'what information and knowledge are not captured but should be otherwise during the design process'. We are presently analysing more experiments conducted to validate results using elaborated statistical technique.

References

Blessing, L., Chakrabarti, A., & Wallace K. (1995). A design Research methodology. *Proc. Int. Conf. Engineering design*, 502-507.

Bonnardel, N., & Zenasni, F. (2010). The impact of technology on creativity in design: An enhancement? *Creativity and innovation management*, 19(2), 180-191.

Chakrabarti, A., Sarkar, P., Leelavathamma, N. B. (2005). A functional representation for aiding biomimetic and artificial inspiration of new ideas, *AI EDAM*, 19, 113-132.

Cham, J. G., & Yang, M. C., (2005). Does sketching skill relate to good design? In *Proceedings ASME 2005* International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Long Beach, California, ASME, Philadelphia.

Fish, J., & Scrivener, S. (1990).Amplifying the minds eye: sketching and visual cognition.Leonardo, 23, 117-126.

Goel, V. (1995). Sketches of thought. US: MIT.

Goldschmidt, G. (1994). On visual design thinking: the vis kids of architecture. *Design Studies*, 15, 158-174.

Ibrahim, R., & Rahimian F. P. (2010). Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction*, 19, 978–987.

Ibrahim, R.., & Paulson Jr, B.C. (2008). Discontinuity in organisations: identifying business environments affecting efficiency of knowledge flows in PLM, *Intl. J. Prod. Lifecycle Manage.* 3, 21–36.

Kwon, J., Choi, H., Lee, J., & Chai, Y. (2005). Free-Hand Stroke Based NURBS Surface for Sketching and Deforming 3D Contents. *PCM 2005*, Part I, LNCS 3767.

Lawson, B. (1997). How designers think: The design process demystified. Oxford, UK: Architectural Press.

Lawson, B. (2002). CAD and Creativity: Does the Computer Really Help? Leonardo, 35(3), 327–331.

Maher, M. L., Rosenman, M., & Merrick, K., (2007). Agents for multidisciplinary design in virtual worlds. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 21, 267–277.

Renzulli, J. S., Owen, S. V., & Callahan, C. M., (1974). Fluency, flexibility, and originality as a function of group size. *The Journal of Creative Behavior*, 8(2), 107-113.

Robertson B.F., Walther, J., & Radcliffe, D.F., (2007). Creativity and the use of CAD tools: Lessons for engineering design education from industry. *Journal of Mechanical Design*, July, 129, 753-760.

Robertson, B.F., & Radcliffe, D.F. (2009). Impact of CAD tools on creative problem solving in engineering design. *Computer-Aided Design*, 41, 136-146.

Rosenman, M. A., & Gero, J. S., (1996). Modelling multiple views of design objects in a collaborative CAD environment. *Computer-Aided Design*, 28(3), 193-205.

Sarkar, P., & Chakrabarti, A. 2011. Assessing design creativity. *Design Studies*, 32, 348-383.

Schön, D. (1983). The reflective practioner: How professionals think in action. Surry England: Ashgate Publishing Limited.

Srinivasan, V., & Chakrabarti, A. (2010). Investigating Novelty-Outcome Relationship in Engineering Design. *AI EDAM*, 24, 161-178.

Stacey, M., & Eckert, C. (2003). Against ambiguity. *Computer-Supported Cooperative Work*, 12, 153-183.

Stones, C. M., & Cassidy, T. (2007). Comparing synthesis strategies of novice graphic designers using digital and traditional design tools. *Design Studies*, 28, 59-72.

Stones, C., & Cassidy, T. (2010). Seeing and discovering: how do student designers reinterpret sketches and digital marks during graphic design ideation?, *Design Studies*, 31, 439-460.

Whitefield, A., (1986). An Analysis and Comparison of Knowledge Use in Designing with and without CAD, in Smith A., (ed.) *Proceedings of CAD*, Butterworth, London.

Won, P. H. (2001). The comparison between visual thinking using computer and conventional media in the concept generation stages of design. *Automation in Construction*, 10, 319-325.