30th eCAADe
CONFERENCE PRAGUE 2012

Czech Technical University in Prague, Czech Republic

vol. 2

PHYSICAL DIGITALITY

Edited by Henri Achten, Jiří Pavliček, Jaroslav Hulín, Dana Matějovská

Editors
Henri Achten
Jiří Pavliček
Jaroslav Hulín
Dana Matějovská
Czech Technical University in Prague, Faculty of Architecture, Czech Republic

1st Edition, September 2012

Physical Digitality – Proceedings of the 30th International Conference on Education and research in Computer Aided Architectural Design in Europe, Prague, Czech Republic, September 12-14, 2012, Volume 2. Edited by Henri Achten, Jiří Pavliček, Jaroslav Hulín, Dana Matějovská. Brussels: Education in Computer Aided Architectural Design in Europe; Prague: České Vysoké Učení Technické v Praze.

ISBN 978-9-4912070-3-7 (eCAADe)

Publisher: eCAADe (Education and research in Computer Aided Architectural Design in Europe) and ČVUT, Faculty of Architecture

www.ecaade.org

Cover design: Jakub Čaja

eCAADe 2012

Volume 2

Physical Digitality

Proceedings of the 30th International Conference on Education and research in Computer Aided Architectural Design in Europe

September 12-14 2012
Prague, Czech Republic
Czech Technical University in Prague, Faculty of Architecture

http://ecaade2012.molab.eu

Edited by
Henri Achten
Jiří Pavliček
Jaroslav Hulín
Dana Matějovská

Computer aided cognition and creativity: a three year monitoring exercise

Raid Hanna[1],
[1]*Mackintosh School of Architecture, Glasgow, Scotland, UK*
[1]*R.Hanna@GSA.AC.UK*

Abstract. *This paper tracked the progress of 24 students who were 'intensive' users of CAD and 26 'occasional' CAD users over a 3 year period. At the end of each year, student attitudes toward creativity dimensions were monitored, using questionnaires and semi-structured interviews. The collected data was analyzed with the Statistical Package for Social Sciences (SPSS). The statistical tests displayed a significant difference between both groups in terms of ideation fluency and ideation flexibility ($P<0.05$). Within the intensive CAD group the tests also yielded significant differences between years ($P<0.05$). Ideation fluency correlated positively with years of study and was influenced by CAD and design maturity both as a 'main effect' and as an 'interaction'. The cognitive preference for complexity as a design trait in the intensive group also correlated with the increased complexity of the digital tools used; preference for low complexity correlated with the use of direct CAD tools whereas higher levels of complexity correlated with the deployment of parametric and generative tools.*
Keywords. *Creativity; ideation; CAD; repeated measures; statistics.*

CREATIVITY, ITS MEASUREMENT AND IMPACT OF SOFTWARE

Creativity is the ability to produce work that is novel, original, unexpected and appropriate, i.e. useful. (Sternberg 1999) On its own and sometimes allied with originality, creativity has always featured in architectural design definitions. The design process has often been described as an embodiment of many intangible elements including creativity, intuition and imagination, which are critical to quality. (Zeisel 1981)

The literature on creativity is wide, deep and varied with emphasis on four domains: process, product, person and context (environment).

Creativity's link to personality has been thoroughly researched; an example is the pioneering work of Barron (1969) and MacKinnon's study linking the creativity of three groups of architects to 'variance' in preferences on conformity to internal or external standards of architectural excellence.(MacKinnon 1965) Using the Barron-Welsh Art scale, Barron and Welsh administered a 400-item test to a sample of artists and non-artists. Artists were found to prefer figures that are 'complex, asymmetrical, freehand rather than ruled and moving in their general effect'. Artists described them as organic.(Barron 1953)

Allied to creativity and central to design is 'intuition', the immediate apprehension of a problem, which is linked to creative traits by Gough (1964) as 'the creative personality is intuitive and emphatic', and is also associated with duration by Bergson (1965) who suggests that intuition cannot last.

A number of tests have been devised, validated and advocated for measuring creativity. One of the most common ones is RAT (remote association test), word association, where the subject is usually given three words and required to find a fourth word which could provide an associative link between the three unrelated ones. (Mednic 1962) However, Datta (1964) questioned the suitability of this method for all professions. Datta concluded that 'the production of remote verbal associations is not as important a component of behavioural creativity for professional engineers (and perhaps architects and scientist) as it maybe for psychology and design'. (Datta 1964)

Torrance's seminal work identified four main parameters for creativity: fluency (generating a volume of ideas); flexibility (to do with the variety of ideas); originality (uncommonness of ideas); elaboration (advancing an idea).(Torrance 1966) Meanwhile, Runco and Chand (1995) developed a two-tier creativity model. The primary tier has three components: problem finding, ideation (fluency, flexibility, originality), and evaluation. The secondary tier has two components: knowledge, declarative and procedural, and motivation. Two additional modes of thinking, convergent and divergent, were widely reported in the literature to have influenced creativity in problem solving.(Runco & Albert 1985) Convergent thinking follows a single prescribed path to arrive at a single solution to the problem. Divergent thinking on the other hand is speculative as it explores ideas and combinations to arrive at 'possible' solutions to the problem.

Finke, Ward & Smith (1992) studied the role of imagery based cognition in creativity, and introduced a problem solving model, which has two phases: generative and exploratory. In the generative phase one constructs mental representations, called pre-inventive structures, to promote creative discovery. The pre-inventive structures and their properties are then interpreted in the exploratory phase to arrive at desirable solutions and products. Furthermore, Bartlett maintains that external visual stimuli from objects are related to pre-existing structures in the brain, both of which are used to provide useful information for creative problem solving.(Rowe 1991)

In summary, the bulk of research has focused on tests of creativity as a 'process' which uses a battery of measures that examine verbal abilities, visual abilities and unusual uses test. In comparison, research on the creativity of 'products', is less in volume. Amabile (1982) attempted to develop a 'consensual' definition of creative product which aimed at establishing a reliability assessment from a group of judges on the creativity of products. Amabile's assessment tool for creative products had three dimensions: creativity judgement, technical judgement and aesthetic judgement. However, both the idea and practice of using appropriate judges to assess a product was pioneered by Mackinnon (1962) who examined the traits of personality associated with creativity in architecture by independently asking five professors of architecture in the US to nominate the forty most creative architects in the US. According to Mackinnon, it was important to reach an agreement between the five experts on 'who are the more and who are the less creative workers in a given field of endeavour'. Based on the results from earlier work, Amabile (1983) established a component framework to encapsulate and conceptualise creativity. The framework comprised three components: 'domain relevant skills', 'creativity' related skills and 'task motivation'. The latter component, motivational variables in creativity, though important, received little research attention.

To examine the role of analogical thinking on creativity, Bonnardel (2000) conducted an experiment with 10 volunteer students in Applied Art from the Technical School of Marseille, France and concluded that analogical reasoning 'as a source of inspiration' is very important for creativity and also having cognitive 'constraints' can help the 'emergence' of new ideas.

On architectural creativity, Seventeen graduating architectural students from Princeton University were rated in terms of creativity by two professors familiar with their work, and the scores were correlated with a battery of creativity tests.(Karlins, Schuerhoff and Kaplan 1969)This study found that rated architectural creativity did not correlate with 'measures of academic aptitude' such as class rank and grades, but was related to the 'quality of their design projects and their performance on the spatial factor test'. The spatial factor involves two parameters: spatial orientation and visualisation.

The above research, however, did not examine architectural creativity and computers. Therefore there is a need to review the literature on the impact of CAD tools on domains of creativity in problem solving. After a thorough literature review, a handful of papers were found that dealt with the influence of CAD on creativity.

In a PhD investigation the relationship between creativity and CAD was empirically tested, using interviews, protocol analysis, observations, questionnaires and design diaries.(Musta'amal 2010) The results showed an occurrence of creative behaviour when CAD was used to solve design problems. Novelty as a design behaviour was recorded in the design process in design diaries from two case studies. Furthermore, findings from data analysis associated creativity of design outcomes, i.e. products, with the use of CAD.

The impact of computer based tools on decision support systems (DSS) that would enable problem solvers to develop more creative solutions was examined experimentally using a three group design. (Elam and Mead 1990) With regards to creativity enhancing-DSS, the study posed two questions: do computers influence decision making processes of their users and whether 'those systems could affect the creativity' of users' decisions. From the finding it was concluded that both 'questions were answered positively'. However, the study noted that the software can 'undermine creativity as well as enhance it' and calls for understanding the manners in which the software affects both creativity and the decision making process. The above study was replicated and expanded upon in a laboratory experiment where conditions around software treatment were controlled in a two group design. One group of subjects was given paper-and-pencil and no software while the other used the creativity-enhancing software. (Marakas and Elam 1997) The findings confirm that increased creativity is affected to great extent by the 'process' deployed by the decision maker rather than the 'vehicle' used. The study also highlighted the importance of the user in enhancing their creativity by understanding the 'creativity-enhancing software' and the 'creativity-enhancing process'.

Candy (1997) examined the relationship between creative support systems such as computers, models of cognition and process and qualities of creative work. This study concluded that to support the needs of the creative user the support system has to provide and facilitate three functions: knowledge appraisal and addition, visualisation, and collaboration between teams. The study argues for a better understanding of creativity and, in turn, calls for the pursuit of 'field' studies of creativity where subjects are observed in usual settings, rather than under controlled laboratory situations.

In engineering, several studies were found dealing with the influence of computation on the creativity of the design process. Robertson and Radcliffe's (2009) survey of engineers confirmed that CAD tools as a design media have a positive impact on improved communication and visualisation as they proved to be very useful. On thinking constrains, the computer was found to drive the subject toward 'perfection' in problem solving. The study also reported that the constant use of CAD did not influence motivation in a negative way that may hinder the creative potential of designers. Finally, on 'premature fixation', that a CAD tool can force the designer to adopt a specific solution, the study found no evidence of this being 'a widespread problem' among CAD users. Meanwhile, Holt (1993) has identified a number of non- commercial CAD tools that are thought to 'facilitate creative thinking in problem solving activities' in design. Although his investigation is theoretical in nature it makes some interesting predictions regarding the future development of CAD tools in that any development should focus on creating a computer supported design environment that can provide specialised knowledge based systems where designers can test their design hypothesis. Gomez et al. (2006) highlight two important issues in software design, which are important for creativity: analogy and retrieval. They maintain that 'analogy is an important reasoning process in creative design' and to introduce creative analogies, software should facilitate the 'semantic' or 'structural' retrieval of candidate analogies from knowledge based systems. Meanwhile, Nakakoji, Yamamoto and Ohira (2000) introduced a new type of creativity, called 'collective creativity' and developed two computer systems that support 'designer's collective creativity by accessing 'representations ' generated by other designers 'in the community'. They also observed the way that designers interacted with both systems and concluded that any system that is intended to support collective creativity has to encompass design knowledge which has a context, is reliable and creates motivation, i.e. make designers love what they are doing. Furthermore, Tennyson and Breuer (2002), after an empirical research, conclude that computer based 'dynamic' simulation can enhance creative problem solving techniques. The simulation process which they introduced is a three stage process. In the first instance the simulation provides the user with useful information about the context of the problem. The second stage requires the users to provide their own solution to the problem. In the final stage the simulation evaluates the submitted proposal and offers some feedback.

Finally, recent research findings on the use of different design media, i.e. sketch/ word/ model/ computer) by two small groups of designers have challenged and refuted two long held notions: that conventional sketching is the primary conceptual design tool and that 'computing is unsuitable for conceptualization.'(Jonson 2005)

In architecture there were even fewer empirical studies that dealt with the influence of the computer, or CAD tools on creative cognition. A study by Hanna and Barber (2002) measured attitudes of architecture students in the studio toward the design process at two points in time: before and after using the computer. The analysis revealed a significant difference in attitudes toward design variables when subjects were asked to use CAD in design. The results suggest that the use of CAD has yielded a positive influence on the creative process. CAD seems to: facilitate the 3D visualisation and testing of design concepts, increase ideation fluency and help the conception of complex geometry.

CASE STUDY AND FINDINGS

The aim of the case study is to test two hypotheses with regards to the impact of using CAD on attitudes towards design creativity. The first hypothesis postulates that there will be a significant difference in attitudes towards between intensive and occasional users of CAD as to how design creativity is influenced by the 'extent' of CAD use over a prolonged period of time. The second hypothesis, which is more important, deals with the 'intensive' group of CAD users over a three years period. It assumes that there will be a significant difference in attitudes toward creativity between 'intensive' groups caused by different years of 'exposure' to CAD. The logic behind both hypotheses is that CAD tools will do what all tools do; open up channels of opportunity in one direction and cut off other possibilities. To test both hypotheses the study followed and monitored the behavior of 24 students who were 'intensive' users of CAD and 26 students who were 'occasional' users of CAD over a period of 3 years. The occasional group was used as a control group. Their attitudes towards the impact of CAD on design creativity were measured over 3 years using questionnaires and semi-structured interviews. The Statistical Package for Social Sciences (SPSS) was used to mine the collected data and compute statistically the 'variance' within each group and between groups. The research design is called 'repeated measures' as the study measures the 'same variables' over 3 years.

As mentioned earlier, Torrance identified four dimensions for creativity: ideation fluency, ideation flexibility, originality and elaboration. However, the study uses 'ideation fluency' as the main indicator for creativity for two reasons. Firstly, the semi structured interviews with students revealed that out of the four parameters, ideation fluency as a concept was the easiest to comprehend while originality was the most difficult concept to understand. Secondly, there is an ample amount of literature which highlights the significance of ideation fluency to both originality and creativity in problem solving. (Wallach and Cogan 1965; Moran et al. 1984) Additionally, in an empirical investigation, Moran et al. (1983) conclude that 'quantity of ideational output was related to its originality'. The researchers explain the link between the two concepts and suggest that 'there is a relationship between the quantity of response and its quality such that the generation of many potential solutions leads to the production of a few highly original solutions that are statistically unusual.' Furthermore, Mednick (1962) examined the associative basis of creative process and argued that 'the greater the number of associations that an individual has to the requisite elements of a problem, the greater the probability of his reaching a creative solution.'

A further support for the link between 'volume' of ideas and originality came from Milgram and Arad (1981) who examined the issue in a case study among college students (N=50). Their findings supported the 'validity of conceptualisation of original problem solving based on ideational fluency and specify the critical role of unusual responses of low quality.' In another experiment, Milgram (1983) used a larger sample of 142 middle and lower class children (7-13 years old) to examine the validity of 'using measures of ideational fluency' as predictors of 'original problem solving'. The findings confirmed the existence of high relationship between quantity and quality of ideas as they indicated that 'the ability to generate many unusual high quality responses to problems…is a valid predictor of the ability to produce original solutions.'(Milgram 1983)

This research used the ANOVA statistics, Table 1, to measure the variance in ideation fluency between the two groups over a 3 years period. The Eta squared was calculated to establish the 'effect size' of this variance.

The table shows that the variance between the two groups on the impact of CAD on the volume of design ideas produced, is significant ($P<0.05$). The Eta squared calculations gave 0.08 for YR1, 0.128 for YR2 and 0.104 for YR3. According to Pallant (2010) the first effect size (YR1) is medium whereas the second and third figures are both large. More important for this research, is to examine the variance in ideational fluency between subjects within each year of the intensive group. Two variables which are deemed to have an impact on ideation are introduced. These are: 'CAD as an ideation factor' and 'design maturity'. It could be that the difference between subjects in ideation fluency is partly due to the fact that some students spend more time on design than others, acquire more design skills and 'maturity' and in turn produce a larger volume of design ideas. Design maturity was measured by knowing the time in hours students usually spend working on design each day. Using Factorial ANOVA the research examined the impact of each variable on ideation fluency as a 'main effect' and the joint impact of both as an 'interaction effect'. The significance levels, Table 2, confirm the presence of a main effect relationship between CAD as an ideation factor and the dependent variable of ideation fluency (Sig.=0.000, $P<0.05$). Design maturity did not produce any main effect on ideation fluency (Sig.=0.089, $P>0.05$). However, there was a significant interaction effect between CAD as an ideation factor and design maturity (Sig.=0.012, $P<0.05$). This interaction is presented in Figure 1. The 2 hour line shows little difference between the Yes/No response as to whether CAD plays an important role on ideation or not. As students' work rate on design increased to 4 hours and more, the gap between the Yes and the No response increased significantly. This implies that design maturity has an 'interaction' effect on ideation fluency.

The findings on YR3, Table 3, show two main effect relationships but no interaction effect between design maturity and CAD as an important ideation factor. The 'main effect' impact of design maturity on ideation fluency (Sig.=0.42, $P<0.05$) implies that ideation fluency can also result from an increased number of hours working on design, i.e. increased design maturity, as well as CAD being a factor. The effect size for this is calculated using Partial Eta squared, Table 3. The results give a figure of 0.297 (out of 1) for design maturity and 0.479 for CAD as a factor for ideation. If

Table 1
The Analysis of variance between the two groups across the three years

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Number of design ideas (YR1)	Between Groups	5.231	1	5.231	4.296	.044
	Within Groups	58.449	48	1.218		
	Total	63.680	49			
Number of design ideas (YR2)	Between Groups	8.534	1	8.534	7.021	.011
	Within Groups	58.346	48	1.216		
	Total	66.880	49			
Number of design ideas (YR3)	Between Groups	6.433	1	6.433	5.565	.022
	Within Groups	55.487	48	1.156		
	Total	61.920	49			

Table 2
Factorial ANOVA (YR1): main effect on ideation fluency (dependent variable) and interaction between CAD and design maturity

Tests of Between-Subjects Effects

Dependent Variable:Number of design ideas (YR1)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	34.592ª	5	6.918	17.196	.000
Intercept	92.810	1	92.810	230.689	.000
designmaturityYR1	2.238	2	1.119	2.782	.089
CADasideationfactorYR1	15.517	1	15.517	38.569	.000
designmaturityYR1 * CADasideationfactorYR1	4.592	2	2.296	5.707	.012
Error	7.242	18	.402		
Total	182.000	24			
Corrected Total	41.833	23			

a. R Squared = .827 (Adjusted R Squared = .779)

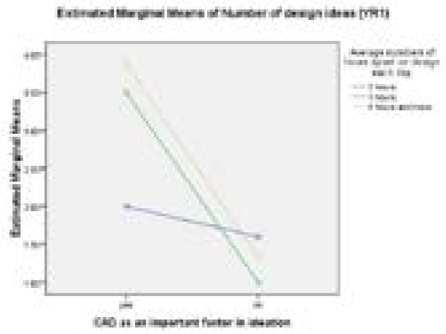

Figure 1
The interaction effect between numbers of hours spent on design and CAD as an important ideation factor

we add both figures we get 0.776 for both, implying that 77% of variance in attitudes toward ideation fluency is caused by these two variables. The other 23% of variance could be caused by differences in design knowledge (procedural and declarative) and/or motivation. (Runco and Chand 1995)

The mean number of design ideas (fluency) achieved by each year with the aid of CAD in the intensive group is presented in Table 4.

Table 3
Factorial ANOVA (YR3): main effect on ideation fluency (dependent variable) and interaction between CAD and design maturity

Tests of Between-Subjects Effects

Dependent Variable:Number of design ideas (YR3)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	24.458ª	5	4.892	8.097	.000
Intercept	134.533	1	134.533	222.675	.000
designmaturityYR3	4.587	2	2.293	3.796	.042
CADasideationfactorYR3	10.007	1	10.007	16.563	.001
designmaturityYR3 * CADasideationfactorYR3	.657	2	.329	.544	.590
Error	10.875	18	.604		
Total	302.000	24			
Corrected Total	35.333	23			

a. R Squared = .692 (Adjusted R Squared = .607)

Table 4
The mean, median and standard deviation of design ideas per scheme across years (intensive group)

Statistics

		Number of design ideas (YR1)	Number of design ideas (YR2)	Number of design ideas (YR3)
N	Valid	24	24	24
	Missing	0	0	0
Mean		2.4167	2.7500	3.3333
Median		2.0000	3.0000	3.0000
Std. Deviation		1.34864	1.29380	1.23945

Table 5
Chisquare and Significance values

Test Statisticsª

N	24
Chi-Square	24.776
df	2
Asymp. Sig.	.000

a. Friedman Test

In this research design ideas are not considered to be equal to design solutions. A design idea is any strategic decision or a design move that has contributed significantly or led toward finding a solution to the design problem. The difference between years 1,2 and 3 was examined further using Friedman's test for 3 related samples (repeated measures) and the results show that the Chi-Square value is high and above the critical of 9.21 for df=2 confirming that the difference between the three groups is statistically significant.

Table 6
Factorial ANOVA (YR3): main effect on ideation flexibility (variety) and interaction between CAD as ideation factor and design maturity

Tests of Between-Subjects Effects

Dependent Variable: Rate the variety between design ideas with CAD

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	17.333ᵃ	5	3.467	5.368	.003	.599
Intercept	142.164	1	142.164	220.126	.000	.924
designmaturityYR3	7.666	2	3.833	5.935	.010	.397
CADasideationfactorYR3	3.088	1	3.088	4.782	.042	.210
designmaturityYR3 * CADasideationfactorYR3	2.245	2	1.122	1.738	.204	.162
Error	11.625	18	.646			
Total	269.000	24				
Corrected Total	28.958	23				

a. R Squared = .599 (Adjusted R Squared = .487)

Table 7
The relationship between the dominant type of CAD tool and cognitive design complexity

Correlations

			Dominant type of CAD tool used	The impact of CAD on cognitive complexity
Spearman's rho	Dominant type of CAD tool used	Correlation Coefficient	1.000	.633**
		Sig. (2-tailed)	.	.001
		N	24	24
	The impact of CAD on cognitive complexity	Correlation Coefficient	.633**	1.000
		Sig. (2-tailed)	.001	.
		N	24	24

**. Correlation is significant at the 0.01 level (2-tailed).

Ideation flexibility, i.e. the variety between design ideas, was also tested in both groups (intensive-occasional) and computed with the ANOVA procedure in SPSS. The figures of variance on ideation flexibility between the two groups across each year were statistically significant: P=0.041 YR1; P=0.027 YR2; P=0.046 YR3. The main and interaction effects of both CAD as a flexibility factor and design maturity, as independent variables, on ideation flexibility, as the dependent variable, were assessed and the results are displayed in Table 6.

Table 6 clearly shows a 'main effect' impact for each of design maturity (sig.=0.42, $P<0.05$) and CAD as a factor for ideation flexibility (sig.=0.042, $P<0.05$). There was no interaction effect (sig.=0.204, $P>0.05$). The effect size for the impact of design maturity on ideation variety was much greater than that of CAD as an ideation flexibility factor.

The research also briefly examined the notion of 'cognitive complexity' and the impact of CAD on it as a design trait in each group. In the literature cognitive complexity of creative individual is defined as a mechanism that 'enables them to integrate conflicting, ambiguous or novel information'. (Charlton and Bakan 1988, in Runco and Chand 1995). In design this definition can be translated into two types of complexity: mathematical and structural. The mathematical deals with the number of vertices per shape: the more vertices in a shape, the higher its complexity. Structural complexity relates to the difficulty of constructional buildability. The impact of two types of CAD tools, direct and indirect or parametric/generative, on design complexity was examined. With direct CAD such as Rhino, the student can input and draw objects directly on the screen. In parametric/generative CAD the relationship between the designer and the CAD system is more ambiguous where objects are created out of 'related' components 'controlled' by parameters. Students were asked about their preference for complexity as a design trait and at the same time score the type of CAD tools they predominantly use in design. The results are presented in Table 7 and Figure 2. The high correlation coefficient (0.633, $P<0.05$) implies that complexity of tools used had an impact on a preference for cognitive complexity. Parametric/generative tools are more abstract and more difficult to use than CAD tools. Some of the interviews with few specific intensive users revealed that the use of indirect CAD such as Grasshopper has helped them to explore complex façade patterns, morphed surfaces and complex grids, 'generated' through the use of random numbers and mathematical functions.

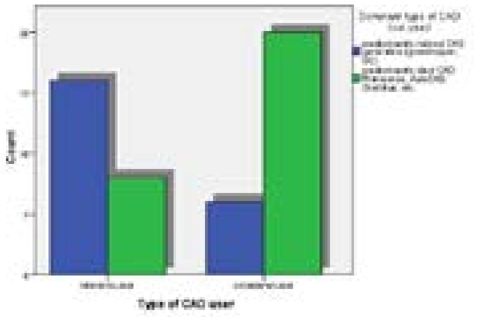

Figure 2
The relationship between the type of CAD user and CAD tool

CONCLUSIONS

Any conclusions drawn from this investigation have to be carefully considered for two reasons. First, the validity of the findings is compromised by the small sample size which will be open to statistical bias. Second, although dimensions of creativity were explained to students through various interviews and tutorials, there is always an element of skepticism whether they fully understood those dimensions. Moreover, further research is needed to carry out a 'protocol analysis' procedure with few subjects and the results from such endeavor can be used to cross examine the results in this investigation. However, some tentative conclusions and research observations are presented. Generally speaking it seems that lengthy 'exposure' to CAD seems to correlate with higher ideation fluency and flexibility. Intensive users generally felt that their creative decision making was somehow helped by CAD. However, the 'interaction effect' for design maturity- measured by the extent of time spent on developing design ideas- (Table 2) in addition to its 'main effect' on design ideation (Table 3) suggest that ideation can be improved through means, and possibly media, other than CAD. The interaction effect for design maturity happened when students were using 3/4 hours daily working on design. Furthermore, it could be that the importance of CAD in generating ideation fluency recedes with more time being allocated to design development.

The nature of CAD tools used can also affect cognitive preference with regards to complexity. Parametric/generative tools, although they can help in exploring complex geometry, could encourage a 'design fixation' toward complex and curvy objects. This may also engender an obsession with 'formal' issues of design at the expense of functional and environmental considerations.

In closing, the study concludes that CAD as a decision support system does affect creativity domains.

REFERENCES

Amabile, TM 1982, 'Social psychology of creativity: a consensual assessment technique', Journal of Personality and Social Psychology, 43(5), pp. 997-1013

Amabile, TM 1983, 'Social psychology of creativity: a componential conceptualization', *Journal of Personality and Social Psychology*, 45(2), pp.357-376.

Barron, F 1953, 'Complexity-Simplicity as personality dimension', *Journal of Abnormal and Social Psychology*, 48 (2), pp.163-172

Barron, F 1969, 'Creative person and creative product', Holt Rinehart and Winston Inc., London.

Bonnardel, M 2000, 'Towards understanding and supporting creativity in design: analogies in a constrained cognitive environment', *Knowledge Based Systems,* 13, pp. 505-513

Candy, L 1997, 'Computer and creativity support', *Knowledge Based Systems*, 10, pp. 3-13.

Datta, L 1964, 'Remote associates test as a predictor of creativity in engineers', *Journal of Applied Psychology*, 48(3), p. 183

Elam, J and Mead, M 1990, 'Can software influence creativity?' *Information Systems Research*, 1(1), pp. 1-23

Finke, R, Ward T and Smith S 1992, 'Creative Cognition', MIT Press, Cambridge.

Gough, H 1964, 'Identifying the creative man', *Journal of Value Engineering*, 2(4), pp.5-12

Hanna, R and Barber, T 2002, 'An inquiry into computers in design: attitudes before-attitudes after', *Design Studies*, 22, pp. 255-281

Holt, K 1993, 'Computer aided creativity in engineering design', *Journal of Engineering Design*, 4(4), pp.371-376

Jonson, B 2005, 'Design ideation: the conceptual sketch in the digital age', *Design Studies*, 26(6), pp. 613-624

Karlins, M, Schuerhoff, C and Kaplan, M 1969, 'Some factors related to architectural creativity in graduating architecture students', *Journal of General Psychology*, 81, pp. 203-215.

MacKinnon, D 1962, 'The nature and nurture of creative talent', *American Psychologist,* 17, pp. 484-495

MacKinnon, D 1965, 'Personality and the realization of creative potential', *American Psychologist*, 20(4), pp.273-281

Marakas, G and Elam, J 1997, 'Creativity enhancement in problem solving', *Management Science*, 43(8), pp. 1136-1146

Mednic, SA 1962, 'The associative basis of the creative process', *Psychological Review,* 69(3), pp. 220-232

Milgram, RM 1983, 'Validation of ideational fluency measures of original thinking in children', *Journal of Educational Psychology,* 75(4), pp. 619-624

Milgram, RM and Arad, R 1981, 'Ideational fluency as a predictor of original problem solving', *Journal of Educational Psychology,* 73(4), pp. 568-572

Moran, JD, Milgram, RM, Sawyers, JK and Fu, VR 1983, 'Original thinking in preschool children', *Child Development,* 54(4), pp. 921-926

Moran, JD, Milgram, RM, Sawyers, JK and Fu, VR 1984, 'Predicting imaginative play in preschool children', *Gifted Child Quarterly,* 28(2), pp. 92-94

Musta'amal, AH 2010, 'An Empirical Investigation of the Relationship of CAD Use in Designing and Creativity through a Creative Behaviours Framework', PhD Thesis, Loughborough University.

Nakakoji, K,Yamamoto, Y and Ohira, M, 2000, 'Computational support for collective creativity', *Knowledge Based Systems*, 13(7-8), pp. 451-458

Pallant, J 2010, 'SPSS Survival Manual', Open University Press, UK.

Robertson, BF and Radcliffe, DF 2009, 'Impact of CAD tools on creative problem solving in engineering design', *Computer Aided Design*, 41, pp. 136-146.

Rowe, P 1991, 'Design Thinking', MIT Press, Cambridge.

Runco, M and Albert, R 1985, 'The reliability and validity of ideational originality in the divergent thinking of gifted and non-gifted children', *Child Educational and Psychological Measurement*, 45(3), pp.483-501

Runco, M and Chand, I 1995, 'Cognition and creativity', *Educational Psychology Review*, 7(3), pp. 243-267

Sternberg, RJ 1999, 'Handbook of Creativity', Cambridge University Press, UK.

Tennyson RD and Breuer K 2002, 'Improving problem solving and creativity through use of complex-dynamic simulations', *Computers in Human Behaviour,*18(6), pp. 650-668

Torrance, EP 1966, 'Torrance Test of Creative Thinking', Personnel, Princeton.

Wallach, MA and Kogan, N 1965, *Modes of Thinking in Young Children,* Holt, Rinehart and Winstons, Inc., New York.

Ziesel, J 1984, 'Inquiry by Design', Cambridge University Press, UK.