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## PARAMETRIC TOOLS AND CREATIVITY IN ARCHITECTURAL PRACTICE

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**Abstract.** This paper empirically tested the relationship between creativity and computing tools in two different architectural practice settings: one that extensively uses parametric tools for design and fabrication and another that predominantly uses conventional CAD tools in design. The paper surveyed 14 parametric practices and 17 non-parametric practices from the UK. The results were statistically analysed using IBM\_SPSS (Statistical Package for Social Sciences). The analysis of variance between the 2 groups revealed significant differences on the four domains of creativity. Statistical variance between the two groups on originality was big. Also the length of time subjects used parametric tools correlated significantly with three measures of creativity (fluency, variety and elaboration). Cluster analysis on design cognition of the two groups showed significant pattern differences on how each group structures the design process.

**Keywords.** Architectural practice: tools: creativity: Variance: SPSS.

### 1. Introduction: creativity and architectural design

Creativity, sometimes on its own and sometime with regards to originality, has always featured in architectural design definitions. Creativity is the ‘ability to produce work that is novel and appropriate.’ (Sternberg 1999)

Review of literature on creativity reveals that the bulk of research falls within the disciplines of psychology and education with little recorded within design disciplines including architecture. Even less has been cited dealing with linking creativity to CAD. The literature on creativity is wide, deep and varied with emphasis on four domains: process, product, person and context.

On the difference between creative and non-creative skills of thinking, Koestler (1964) argues that routine thinking operates on a single plane or

context whereas the creative act cultivates more than one plane, what he calls 'the bisociation of two mutually incompatible contexts' and that maximum levels of creativity are attained when our rational thought is suspended.

Creativity, as a personality trait, has been thoroughly researched; see the pioneering work of Barron (1969). More relevant to architectural creativity is MacKinnon's (1965) work which investigated the link between 'personality' and 'preferences' of 3 groups of architects and their creativity. Architects I (the most creative of the three), were found to be preoccupied with achieving their own standards of excellence rather than making impressions on others. Architects III (least creative) seemed to have others as their source of inspiration and closely followed standards set by their profession. Using the Barron-Welsh Art scale, Barron and Welsh administered a 400-item test to a sample of artists and non-artists. They found that artists preferred organic figures that are 'complex, asymmetrical, freehand' rather than 'rules and moving in their general effect'. (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 'to think intuitively is to think in duration'.

## **2. Measuring creativity and impact of software**

RAT (remote association test), word association is one of the most common tests for creativity; the testee 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) empirically questioned the suitability of this method for all professions and 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 measures for creativity: fluency (generating a volume of ideas); flexibility (to do with the variety of ideas); originality (uncommonness of ideas); elaboration (ability to progress an idea). (Torrance 1966) Runco and Chand (1995) developed a two-tier model. The primary tier has three components: problem finding, ideation (fluency, flexibility, originality), and evaluation. The secondary tier has two components: knowledge- declarative (of facts) and procedural (know-how), and motivation.

Finke et al (1992) examined non-verbal, i.e. image based constructs of creativity and introduced a two phase problem solving model. In the generative phase one constructs mental representations, called pre-inventive struc-

tures, 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. Karlins et al (1969) investigated 17 graduating architectural students from Princeton University and found that rated architectural creativity correlated with their performance on the 'spatial factor test'. The spatial factor involves two parameters: spatial orientation and visualisation.

Using interviews, protocol analysis, observations and design diaries Musta'amal (2010) 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 and findings associated creativity of design outcomes (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 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 could 'those systems affect the creativity' of users' decisions? The study concluded that both questions were answered positively and noted that the software can 'undermine creativity as well as enhance it' and called for understanding how the software affects creativity and the decision making process.

Candy (1997) concluded that to support the needs of the creative user the CAD support systems has to facilitate three functions: knowledge appraisal and addition, visualisation and collaboration between teams. The study also calls for the pursuit of 'field' studies of creativity where subjects are observed in *usual settings*, rather than under controlled laboratory situations.

On the creativity of the engineering design process in a sample of surveyed engineers, Robertson and Radcliffe (2009) 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 constraints, 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.

### **3. Parametric computing**

Parametric modelling (PM) enables the creation of 3D models of buildings with embedded and linked parameters; a change in the values inside the pa-

rameters affects the overall description (form) of a geometrical entity. This makes PM an ideal tool for the generation of multiple design variants.

PM such as Grasshopper and Micro station's Generative Components (GC) has an obvious data tree where the association between parameters and components is visually apparent.

Recently many offices opted to create groupings for advanced geometry research and surface topology. Examples include Arup's Advanced Geometry Group (Bosia 2011) and the Computational Geometry Group in Kohn Pedersen Fox Associates (KPF). Additionally, a link between PM, complex geometry and digital fabrication has been reported in the literature. PM has the ability to produce complex forms 'with intuitively reactive components' permitting designers to convey and fabricate structures previously too 'laborious and geometrically complex to realise'. (Pitts and Datta 2009)

On the need for a tool which offers both flexibility and speed Salim and Burry (2010) asserted that the deployment of PM has improved both 'pedagogy and practice of architectural design.' Yet data flow programming, the norm in parametric tools, offers little flexibility in changing the relation between parameters, a known weakness in parametric tools. (Davis et al 2011)

Schnabel (2007) advocates the use of parametric techniques to create solutions to problems at the early design stage and suggests that PM tools 'allow a deeper comprehension of the design objectives' and helps designers in solution finding. More, Aish and Woodbury (2005) suggest: parameterization can boost search for context adapted designs, can help unearth 'new forms' and form-making, can save time for change and reuse, and can produce better understandings of the conceptual structure of the artefact being designed'. As disadvantages, they list: 'additional effort' and the amplification of 'complexity of local design decisions'. Holzer et al (2007) pointed out the limitations in the use of PM at the early design stage: difficulty of constructing an overall parametric model that can cope with the level of alterations demanded by the multidisciplinary design team and the difficulty to maintain the logical association between data structure and design hierarchy.

Hudson (2008) suggested that while the theoretical literature on PM focuses on their use at the conceptual design stage the evidence from observing practice indicates that their deployment occurred at the design development stage rather than at the conceptual stage. Shepherd (2011) cited two main advantages when the building form is formulated using parametric rules between objects rather than the conventional way of using CAD to model a building through entities such as lines. These are: a significant improvement in workflow between the architectural and engineering teams which resulted from sharing a single parametric model and the speed of structural design optimisation. Hudson (2009) argues that the process of de-

veloping a parametric model can begin with ‘incomplete knowledge of the problem’; PM may well be possible at the early conceptual design stage.

Another area of design where PM became a very potent tool is the creation of ‘patterns’ for facades in buildings. Schumacher (2009) argues that ‘articulation is the central core competency of architecture’ and designed patterns provide one of the most powerful means for ‘architectural articulation.’ He predicts a ‘new era of parametric architecture’ where the use pattern as a source of innovation will yield a high level of design articulation in building facades.

In summary, the literature review reveals that some of the claims regarding PM are conflicting and in some cases rely on anecdotal evidence. More importantly we should aim to ascertain whether parametric tools do help or hinder the creative decision making of problem solving in design.

#### **4. Case study and findings**

The survey explored various CAD issues in architectural practice, namely: creativity domains and type of tools (parametric vs conventional CAD); the use of PM at the early design stage; the design activities targeted by CAD. Using SurveyMonkey, questionnaires were designed and distributed on-line to 45 practices from the UK who agreed to take part in the survey. However, the study received completed questionnaires from only 31 offices: 14 described their CAD activities as ‘mainly parametric’ (used Grasshopper and GC) and 17 suggested that they use CAD in a conventional manner (non-parametric: used AutoCAD/ Rhino/ ArchiCAD/ Microstation). The returns were analysed using IBM\_SPSS. The study examined the difference between the two office types on 4 creativity measures (ideation fluency, flexibility (variety), ideation originality and idea elaboration (advancement of an idea). (Torrance 1966)

The first test used was that of ANOVA (Analysis of Variance), Table 1, to establish whether or not the two groups are indeed statistically different. The table shows that the two group are different on the 4 measures of creativity with Significance levels  $<0.05$ . In other words one group considered CAD to be more significant in achieving the 4 creativity measures than the other. The strongest difference (sig.= 0.000) between the 2 groups was on the fourth measure of creativity (advancement of an idea).

Table 1. Analysis of Variance (ANOVA) between the two groups

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
CAD does help/enhance originality (uncommonness)	Between Groups	7.108	1	7.108	7.150	.012
	Within Groups	28.828	29	.994		
	Total	35.935	30			
CAD helps in ideation fluency	Between Groups	4.057	1	4.057	5.049	.032
	Within Groups	23.298	29	.803		
	Total	27.355	30			
CAD helps achieve variety between design ideas	Between Groups	4.294	1	4.294	4.165	.050
	Within Groups	29.899	29	1.031		
	Total	34.194	30			
CAD helps in the advancement of an idea	Between Groups	22.562	1	22.562	50.890	.000
	Within Groups	12.857	29	.443		
	Total	35.419	30			

Figure 1 shows that non parametric practices (92% of 17 practices) intimated that CAD helps the advancement of an idea whereas parametric practices did not feel the same about the usefulness of parametric process (software) for the elaboration of design ideas.

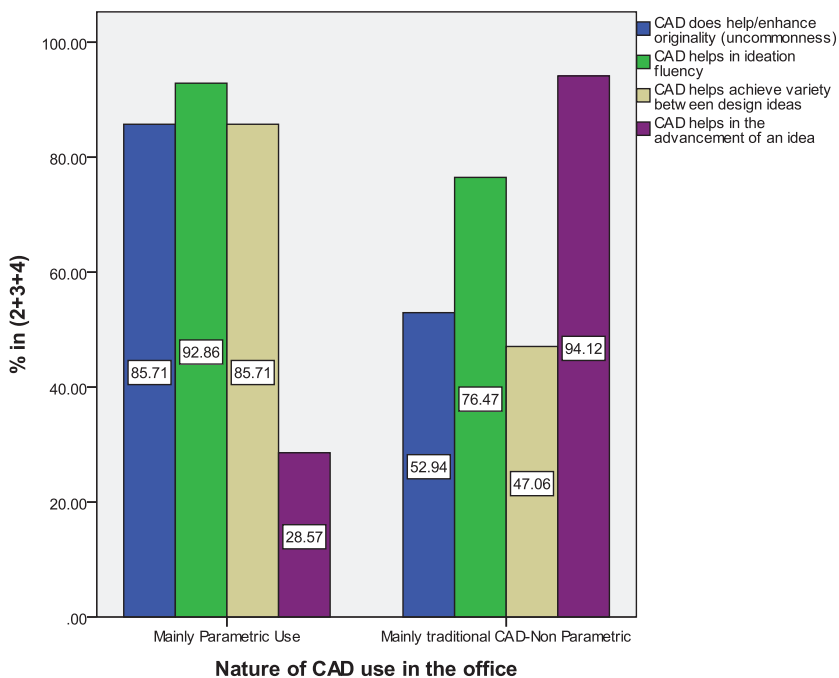


Figure 1. Chart showing percentage of each group's score on the 4 creativity measures (% in categories: 2=slightly, 3=to good extent, 4= to great extent)

When the research mined the data further and computed correlations between variables, it found that the number of years using CAD correlated significantly with three measures of creativity, Table 2 [fluency:  $r=0.400$ , variety:  $r=0.382$ , advancement of an idea:  $r=0.644$ ]. Also Table 2 represents the response from experienced individuals with the highest number of years regarding CAD usage. On ideation fluency, though there was a percentage difference but this small and could have been slightly distorted by the small sample size of parametric offices. From both Table 1 and Figure 1 it is safe to conclude that parametric CAD tools are more effective than non-parametric in enhancing three out of four creativity measures, but are they? Further analysis of data reveals some interesting insights. On the advancement of design ideas the results confirm that traditional CAD has more potential than parametric CAD. One architect intimated: 'what you draw you instantly see in conventional CAD with the presence of materials.'

Table 2. Correlations between creativity measures and number of years using CAD

		CAD does enhance Creative Decision Making	CAD does help/ enhance originality (uncommonness)	CAD helps in ideation fluency	CAD helps achieve variety between design ideas	CAD helps in advancement of an idea
Number of years using CAD (parametric/ conventional )	Correlation	.318	.177	.400*	.382*	.644**
	Coefficient Spearman's rho	.081	.342	.026	.034	.000
	Sig. (2-tailed)	31	31	31	31	31
N						
Correlation is significant at the 0.05 level (2-tailed).*						
Correlation is significant at the 0.01 level (2-tailed).**						

Table 3 shows that the conventional CAD group has a mean of 10.4 years of CAD usage compared to 5.4 years for the parametric group. This implies that the length of time a designer uses CAD can also significantly affect her/his perception of how the tool can help creativity measures. It could be that the length of time in using CAD is more important for the creative decision making process than the type of tool used. On using CAD at the conceptual (early) stages of the design process the ANOVA test did not show any significant difference between the two groups ( $F=1.305$ ,  $Sig.=0.263$  which is  $>0.05$ ). When this variable was correlated with the 'number of years using CAD' the two variables showed a strong and positive correlation across both samples, Table 4: ( $r=0.750$ ,  $Sig=0.000$  which is way below  $0.05$ ). Again this suggests that the experience of the designer in using CAD

is more important than the type of CAD tool used when they decide when to use it, i.e. at the conceptual design stage.

Table 3. Years of using CAD\_ mean value vs office type

<b>Report</b>			
Number of years using CAD (parametric/conventional CAD)			
Nature of CAD use in the office	Mean	N	Std. Deviation
Mainly Parametric Use	5.4286	14	2.17377
Mainly traditional CAD-Non Parametric	10.4118	17	4.22875
Total	8.1613	31	4.23554

Table 4. Correlation Coefficient between 'number of years using CAD' and the 'use of CAD at the conceptual stage of the design process.'

			Number of years using CAD (parametric/conventional CAD)	Do you use CAD at the conceptual Stage of the Design Process?
Spearman's rho	Number of years using CAD (parametric/conventional CAD)	Correlation Coefficient	1.000	.750**
		Sig. (2-tailed)		.000
		N	31	31
	Do you use CAD at the conceptual Stage of the Design Process?	Correlation Coefficient	.750**	1.000
		Sig. (2-tailed)	.000	
		N	31	31

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

The research is using the 'number of years using CAD' as an indicator of the 'level of experience' (competence) in using CAD. It may also be that the level of competence in the use of CAD affects the design strategies adopted by the designer themselves either through adapting their working methods or adapting the software, i.e. extending its usability through scripting or logical programming. There were other design issues tested by this research. The ANOVA test also showed a significant difference (Sig. <0.05) between the two groups in terms of CAD's deployment for: 3D visualisation and modelling, generating design variants/variety and exploring complex surface geometry. Generally the parametric group registered a higher score on those issues than the conventional CAD group. Surprisingly there was no significant difference between the two groups in terms of structural and environmental optimisation of form (Sig.= 0.153 which is >0.05). Again the length



of using CAD correlated significantly with its potential use for: environmental and structural optimisation ( $r= 0.435$ ), creating design variants ( $r= 0.384$ ), exploring complex surfaces ( $r= 0.538$ ), and 3D visualisation and modelling ( $r= -0.693$ ). The negative value of  $r$  suggests that the greater the experience in using CAD the less the subject spent on using it for visualisation. In the conventional CAD group there were eight subjects each with  $> 10$  years' experience in using CAD. Figure 2 shows 2 distinct clusters (representing 2 distinct CAD perceptions), for subjects' responses: the top cluster belongs to the conventional CAD group and the bottom one is for the parametric group. Interestingly, cases 15 and 16, which are part of the conventional CAD clustered with the parametric one. Case 15 and 16 are the highest in terms of 'length of time using CAD' [18 and 16 yrs. respectively].

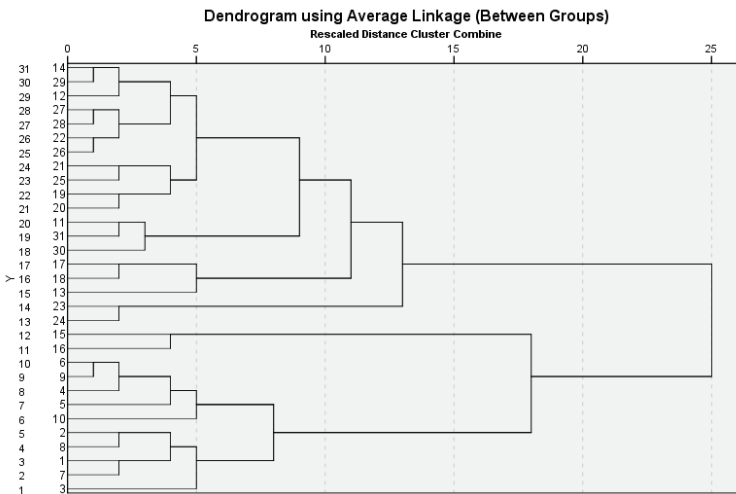


Figure 2. Cluster analysis showing 2 clusters

## 5. Conclusions

A single case study with a limited number of variables and a small sample size can at best refine existing conjectures rather than create new ones. Statistical analysis revealed significant differences between the two groups in terms of creativity measures (originality, fluency, variety and elaboration). However, this relation between type of tool and creativity measures has also been affected by length of time using CAD, which correlated significantly with 3 creativity measures and also with the use of CAD at the conceptual stage of the design process although there was no significant difference between the 2 groups. This implies the length of time using CAD is more important than the nature of the tool itself and how it was used at the conceptu-

al design stages. The length of time using CAD seems to also affect the relationship between type of CAD tools and their potential use for: optimisation, exploring surface complexity, generating design variants and visualisation.

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