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Design reasoning, symbol processing and dematerialised complexity

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This paper examines the impact of using 'digital' media on design thinking. Conjectures about design behaviour were formulated and tested in a 'groups-design' experiment where subjects were given a design task and encouraged to execute it using a Computer Aided Design (CAD) programme. Attitudes toward several design parameters were monitored using observations, questionnaires, and few structured interviews. The completed design schemes were also analysed. The Statistical Programme for Social Sciences (SPSS) was used for measuring attitudes towards three design areas: ideation (including fluency, variety, complexity and creativity), materiality, and light. The findings suggest a difference in attitudes between 'intensive' and 'occasional' CAD users toward the design process. Intensive users suggested that the use of CAD helped their pursuit and preference for complexity as well as their ideation fluency and design synthesis and, in turn, their overall design creativity.

Keywords: dematerialisation, digital processing, creativity, fluency, complexity

1 Introduction

A review of literature on computing and architectural design reveals that there is a gulf in opinion between theoreticians, some view it as a 'medium' that can improve design thinking at a conceptual level while others remain suspicious of its role and regard it merely as a production 'tool' having little or no impact on design thinking and concept formulation.

Furthermore, the difference in opinion can also be observed between prominent practitioners. A similar conflict on the role of computers in design can be detected between two world-class architects. Eisenman's writing identifies two intellectual themes about computers and architecture. Firstly, he highlights the challenges to architecture from the 'electronic paradigm' as 'reality' is defined through simulation and 'appearance', which is valued over 'existence'.[1] Secondly, acknowledging the creative potential of computers, he maintains, "the computer gives you the possibility of constructing objects that you would never do directly from the mind to the hand. We constantly produce models after having conceptualised them using the computer. It is a process of constant refinement."[2]

Gehry, in contrast, adopts a different position in regard to the role of computers in design. Although Gehry acknowledges the potential of the computer as a knowledge-based system for structural design, construction and cost analysis, he remains skeptical about its ability to design, "the computer is a tool, not a partner, an instrument for catching the curve, not for inventing it".[3] As to the notion of 'inventing it', computers can never become autonomous and improve their design skills to match those of a designer.

1 Domus (1992). Visions Unfolding: Architecture in the Age of Electronic Media, N^{o} 734
2 Galofaro, L. (1999), Digital Eisenman, Birkhauser, Basel, pp 21-35
3 Gehry Partners (1999). Architecture + Process, Thames and Hudson, London, p. 25

In his treatise 'new science = new architecture' Jencks argues that there is a shift in thought away from the old Newtonian linear science to other forms of science such as that of complexity, fractals and non-linear systems. He calls for architecture as 'a form of cultural expression' to have a similar shift in the framework of thought. He then cites three 'seminal' buildings of the 1990s to support his thesis. Gehry's Bilbao, Eisenman's Aronoff Centre, Cincinnati and Libeskind's Jewish Museum in Berlin 'are three non-linear buildings that were partly generated by nonlinear methods including computer design', maintains Jencks. He goes on to question the role of metaphor in the three buildings and suggests that "new science = new language = new metaphor".[4] In opposition, Frampton advocates a strong link between architecture and building in the 'material' world. Digital design on the computer is a 'fantasy' unless it conforms to the 'tectonic' - material- requirements of the physical world.[5] This, however, is problematic when using Karl Popper's terminology on the three worlds of knowledge (subjective, objective, material) as conformity to the 'material' world may inhibit the 'subjective' experimentation of minds in the 'objective' world of computers.

However, recent development in software engineering has furthered the capabilities of some CAD packages to a level that increases their creative potential as a conceptual tool at an early design stage. New CAD programs such as Rhinoceros,[6] a NURBS (non uniform rational B-splines) modeler, means that 3D free form organic surfaces and solids can be created intuitively and quickly at the early design stage, thus overcoming serious limitations of traditional polygon modellers. This was accomplished by adding two extra coordinates (U, V) to the traditional three coordinates (X,Y,Z), which in turn improved modeling performance and overcame the 'orthogonal rigidity' of the Cartesian system, an issue rightly criticised by Gomez for representing another form of modernistic rationality.[7]

Also works on 'genetic programming' suggests a new breed of 'evolutionary' CAD tools that can help designs to evolve from scratch through a process of mutation and constant refinement.[8] Evolutionary CAD tools, according to Bentley, "allow the designer to explore numerous creative solutions to problems, overcoming design fixation or limitation of conventional wisdom by generating alternative solutions for the designer".[9]

2 The computer, conceptual design and creativity

The literature on creativity is wide, expansive and exhaustive, ranging from the purely theoretical and descriptive to the significantly operational. Disciplines covered include psychology, education, personality studies, engineering, science and to a lesser extent design studies. Very few studies were found dealing with architectural design and creativity. Even less was found that investigates digital design and creativity.

Almost all 'creativity' definitions revolve around the notion that creativity is the production of ideas, theories, designs, objects, etc. that are 'judged' by experts as being 'novel' and 'valuable'.[10]

On the measurement of 'creativity' the seminal work of both Torrance[11] and Guilford[12] stands out. Torrance's pioneering work identified 4 main dimensions for creativity: 'fluency'- producing a great number of ideas; 'flexibility'- producing a significant variety of ideas; 'elaboration'- development or embellishment

4 Architectural Design (1997). New Science = New Architecture, Profile N° 129

5 Leach, N. ed (2002). Designing for a digital World, Wiley Academy, Chichester

6 Becker, M. (1999). Rhino, Robert McNeel & Associates, USA, pp.85-87

7 Steele, J. (2001). Architecture and Computers, Laurence King Publishing, London, pp 12-24

8 Bentley, P. ed (1999). Evolutionary Design by Computers, Morgan Kaufman, CA, p. 75

9 ibid

10 Bowden, M. (1990). The Creative Mind, Abacus, London, pp 21-35

11 Torrance, E.P. (1966). Torrance Test of Creative Thinking, Personnel, Princeton University Press, p 45

12 Guilford, J.P. (1950). Creativity, American Psychologist, 5, pp 444-450

of an idea; originality- generating ideas that are statistically infrequent.[13]
Runco and Chand elaborated further on Torrance's model and suggested a two-tier model for creativity.[14] The primary tier has three components: problem finding and identification; ideation- fluency, flexibility and originality; evaluation. The secondary tier is that of knowledge both procedural and declarative
Investigation of imagery- non verbal construct- and creative problem solving strategies has been cited in the literature. Finke proposed the 'geneplore' which encompasses two phases: the generative and the exploratory: "in the generative phase, one constructs mental representations, called pre-inventive structures, having various properties that promote creative discovery.[15] These properties are then exploited during an exploratory phase in which one seeks to interpret the pre-inventive structure into meaningful ways".[16]
However, very little research was found that deals with the influence of using digital design methodologies on creativity parameters.

3 The computer and dematerialisation of architecture

Here the opposition is between the 'tectonics' of 'materials, and the information based digital materials. The pro tectonic group, who is largely influenced by Semper, argues that architecture is about building forms that conform to rules of gravity and materials in the real world rather than generating 'fantasy' forms on the screen according to algorithmic rules of the computer.[17]
On the digital side of argument are critics who are inspired by Mies Van der Rhoe and the futurists and their language of 'virtually nil'. For instance, Rahim argues: "experimental architects take advantage of this delay to be truly creative, moving beyond deterministic thought processes. Those rigid methods are limited in their creativity due to their reliance on material modes which are inadequate as creative design processes".[18] Amongst the 'Immaterials' are writings and buildings by architects Rem Koolhaas and Toyo Ito.[19]
The material and the simulated (subjective) world have been considered by Karl Popper, as equally important for the creation and progression of our objective knowledge.[20]

4 The computer and light representation in architecture

The relationship between light as a form giver and architecture has always been intense, reflective and poetic; 'light' being the medium through which architecture revealed itself through time.
Traditional methods and technologies of light representation in architecture, through drawings and models, often fall short of giving a full account of this poetic and visual relationship. For example, architectural drawings though an effective means of representing geometry and the direction of light, are unable to fully represent the 'light' environment inside designed schemes. Drawings and physical models cannot deal accurately with the complex interaction between: light, time, space, texture, colour, inter-reflection and transparency. Boullee, one of few architects who sought a realistic rather than an abstract representation of ideas highlighted these limitations. Writing about the lighting of his design of a Cenotaph for Newton, Boullee reaffirmed the weakness of conventional methods of architectural representation in dealing with light. He stated that 'the effect of this extraordinary image can be only imperfectly represented by the drawing,

13 Torrance, E.P. (1966). ibid
14 Runco, M. & **Chand, I.** (1995). Cognition and Creativity, Educational Psychology Review, 7:3
15 Finke, R.A. (1989). Principles of Mental Imagery, MIT press, pp. 120-145
16 ibid
17 Leach, N. ed (2002). ibid
18 Architectural Design (2000). Contemporary Processes in Architecture, 70:3
19 Puglisi, L.P (1999). Hyper Architecture, Birkhauser, Basel, pp. 5-25
20 Popper, K.H. (1972). Objective Knowledge: An Evolutionary Approach, Oxford University Press, p. 155
21 Perez-Gomez, A. (1983). Architeture and the Crisis of Modern Science, MIT Press, Chapter 4

which can give only a notion of shape'.[21] The photorealistic images which Boullee refers to can be constructed with accuracy using computer aided lighting programmes, which are concerned with creating 'realistic' interior and exterior scenes of buildings in which light, material and texture simulation all play an important role. These programmes deal with lighting design from a different perspective, where the emphasis is not only on the technical side of light but also on its visual dimension. The calculation of light levels in Lux, is secondary to the main aim of producing simulated scenes that are as close as possible to reality.
According to Lord 'architects are especially interested in subjective and aesthetic values that can be evaluated by either building physical models or by photo-realistic computer simulation'.[22]
The manipulation of lighting is by far the most potent element in computer rendering of buildings. For instance, Johnson, an accomplished renderer, asserts that the difference between working with light and ignoring it 'is like the difference between a photograph and a snapshot'.[23] Most programmes rely on either 'ray-tracing' or 'radiosity' algorithms to calculate/simulate accurately the rendered scene producing photo-realistic output.[24]
However, rendering programmes are difficult to use at the early design stage as they require a completed design rather than a sketch plan. Also, emphasis on attractive imagery might distract attention from real design issues to visual artistry, the case of pretty images of mediocre designs. McCullough warned architects against over emphasis on visual accuracy of images, saying: 'allowing visual accuracy to become the sole reality will threaten the artistic spirit of their designs … Art always leaves something to the imagination'.[25]

22 Lord, D. (1990). Computer Aided Lighting, Progressive Architecture, N° 11, pp. 125-129
23 Novitski, B.J. (1993). Software for Rendering, ARCHITECTURE, July, p.119
24 Kalwick, D. (1996). 3D Graphics, Academic Press, New York, pp. 273-300
25 Novitski, B.J. (1993). ibid

5 The Computer: digital presentation and design verbalisation

Traditional methods of presentation include drawing, physical models, photography and collage. Digital methods of architectural presentation are usually a two tier process. Firstly, traditional drawing and computer generated images are manipulated and edited in digital programmes like Photoshop. Secondly, the images are organised in a linear process with a slide show using text, sound and animation to form a storey board. This, linear structure, one could argue, may significantly improve design verbalisation thus providing a more accurate description of the cognitive behaviour. Digital presentations could also have many advantages over traditional methods. For example digital presentations and projections can be viewed from a distance without a loss in the legibility of line drawings. Also, time based design studies like animation fly-through can also be added to digital presentations to overcome the single-view limitation of both drawing and model making.

6 The design problem as a vehicle for investigation: A House on the Coast

The main question addressed by this 'experimental' research is: do computers make a difference to design conception and the creativity of novice designers?
The given task to address the above question asked for the design of a house of up to 200 square metres, at Portencross on the West Coast of Scotland. It was to be primarily a timber structure, although other materials could be used as cladding. The aim was to continue to develop spatial and formal sensibilities and generate an awareness of the creative potential of material and structure in the

design process. The design intentions were to explore the qualitative aspects of space, circulation and materiality and uses of external space in relation to domestic life, how to make use of context and respond to the local climate by taking advantage of site, orientation and the specific characteristics of the location. Visualising and appraising the impact of the proposal on its surroundings also was an issue. In studying materiality notions of structural stability and aesthetic quality together with the impact of material choice on our senses were deemed important.

Although the essential functions of a house are relatively simple, students should have the opportunity to express and create experiences and qualities beyond mere utility. As designers we must become conscious of our contribution to both the natural and manmade environment. This means more than just using environmentally friendly materials in construction. It requires us to consider exactly where we locate our buildings and how we can generate or reinforce a sense of place; how our architecture can contribute to the immediate environment; how by its form and degree of enclosure it can focus our attention on a quality of space and heighten our awareness of the surroundings. It can provide shelter from the elements while enhancing our awareness of light, enrich our experience of the tactile and generate mood and atmosphere. It can allow the user to observe or contemplate, touch our spirit and cause us to be inspired or calmed. As a manmade artifact, a building may be shaped to create visual interest or be symbolic and stimulate thought. As small scale structures they may appear as sculptural objects of elegance or beauty despite their functional origins. Whatever qualities one aspires to as a designer one must remember that a design proposal has to satisfy the user requirements and become the special place they can identify with and call home.

It is often, however, the enhancement of the essential purpose with less tangible qualities that combines to create an architecture that we enjoy and wish to maintain which is truly sustainable.

Students were taught Rhinoceros, a very forgiving NURBS CAD programme, and Flamingo (a rendering and lighting software) over a three weeks period. With Rhinoceros one can quickly construct an array of geometries from simple, linear to very complex organic and fluid surfaces. Taking on board the many issues highlighted by the brief, students were encouraged to use Rhino and Flamingo as a design ‘medium’ alongside sketches and physical models to arrive at a solution(s) to the design problem.

7 Research design and hypotheses

The study formulated two target hypotheses which were put forward for testing. To enable the statistical testing of a hypothesis, an opposite conjecture, the ‘null’ hypothesis, has to substitute the target hypothesis. By refuting the null hypotheses it would be possible to confirm the target hypotheses.

Hypothesis ONE (H^0): There is no difference in attitude towards the design process variables between ‘intensive’ and ‘occasional’ users of the digital process (CAD).

Hypothesis TWO (H^0): The use of digital media makes little difference in improving areas of the design process, namely: conceptual design and creativity; light and material exploration; design representation.

To test the above conjectures the author designed a questionnaire that covered four areas of the design process: creativity during the conceptual design phase, light, issues of materiality, and digital representation. The questions used a 5-point bipolar scale as a device for measuring the encapsulated variables. The questionnaire was administered to 60 students. Returns were received from 33 students only, of whom 12 were found to be intensive users of CAD and 21 were occasional users. The response was coded and the data was statistically mined and tested using the Statistical Package for Social Sciences (SPSS). In addition, personal observations of students while using the computer during the design process were also documented. These, alongside some interviews and design outcomes were analysed statistically to crosscheck the questionnaire returns for internal consistency.

Test Statistics[b]

	use of Rhino help/hinder creativity - type of CAD user
Z	-4.462[a]
Asymp. Sig. (2-tailed)	.000

a. Based on negative ranks b. Wilcoxon Signed Ranks Test

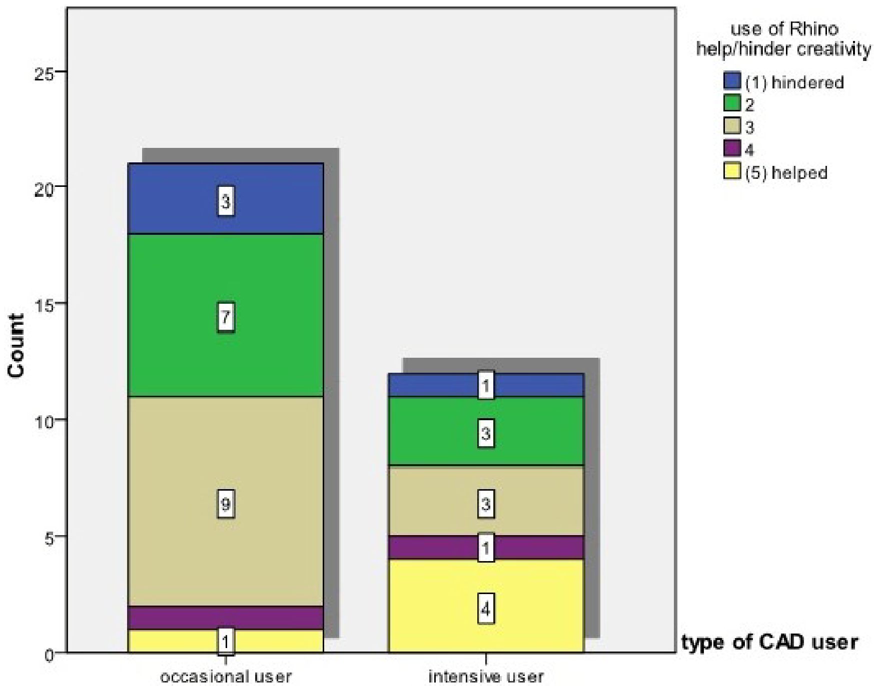

Figure 1 User type, creativity response and test Statistics

8 Findings

8.1 Attitudes toward computer aided conceptual design

The interaction between digital media and design cognition is a complex phenomenon. However, generally one would expect that creativity in design problem solving could be enhanced through the use of digital design software. Close observation of students while working with CAD revealed that intensive users structured the design problem much quicker than occasional users. Intensive users also generated an average of 21 sketches of the design problem compared to an average of 9 sketches produced by occasional users. It took intensive users and average of 16 hours to create the first plan for the house- 12 hours and 40 minutes was the time taken by the quickest while the slowest took 18 hours and 10 minutes. Occasional users spent an average of 26 hours on the computer before creating the first plans. These observations were supported by the statistical analysis. Figure 1 shows the difference and the test statistics for this difference between intensive and occasional users of CAD on whether the computer can help or hinder their design creativity. Around 41% of intensive users (5 students out of 12 with scores of 4 and 5) thought that the computer has helped their creativity compared to only 9% of occasional users. The total percentage of intensive users who scored 3 and more was 67% whereas the total figure for occasional users was 51%.

Table 1 Chi-Square test on user type and 'more than one idea' variable

Cross tabulation: Use of Rhino generates more than one idea * type of CAD user

Count

		type of CAD user		
		occasional user	intensive user	Total
use of Rhino generates more than one idea	yes	9	11	20
	no	12	1	13
Total		21	12	33

Table 2 Statistics based on Chi-Square test- user type and 'more than one idea' variable

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	7.620(b)	1	.006		
Continuity Correction(a)	5.713	1	.017		
Likelihood Ratio	8.685	1	.003		
Fisher's Exact Test				.009	.007
Linear-by-Linear Association	7.389	1	.007		
N of Valid Cases	33				

a Computed only for a 2x2 table

b 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.73

The difference in attitude could be attributed to the fact that intensive users were more skilled in using CAD and consequently they were able to use it more effectively in enframing the design problem during the conceptual stage, hence producing an average of 21 sketches. Such exploration would involve the construction of pre-inventive structures that precedes the spatial and geometrical articulation of design layouts. In the interviews, 8 intensive users suggested that the 'inherent prescriptiveness' of CAD where the manipulation of pre defined 3D objects with Boolean operation (subtraction, union, difference) had immensely helped them generating unusual complex objects from simple platonic forms. The Wilcoxon Signed Ranks Test confirmed that the difference between intensive and occasional users was significant (Significance=000 $P<0.05$).

Participant observation confirmed that intensive users examined an average of 3 ideas whereas occasional users explored an average of 1.5 ideas. Table 1 reveals that 11 intensive users (out of 12) thought CAD did help them generate more than one idea for the scheme. When the difference was examined further for statistical significance, Table 2 confirmed that the number of design ideas and user type were closely associated.

The observations revealed that the number of design ideas explored ranged from 1 (11 students) to 2 (10 students) design ideas. The histogram for intensive user, Figure 2, is ‘skewed’ to the left (11 users who said Yes). The histogram for occasional user is at the centre which suggests that those who replied Yes, were close in number to those who replied no. The difference between the two user groups again was statistically significant (Significance=0.006, $P<0.05$).

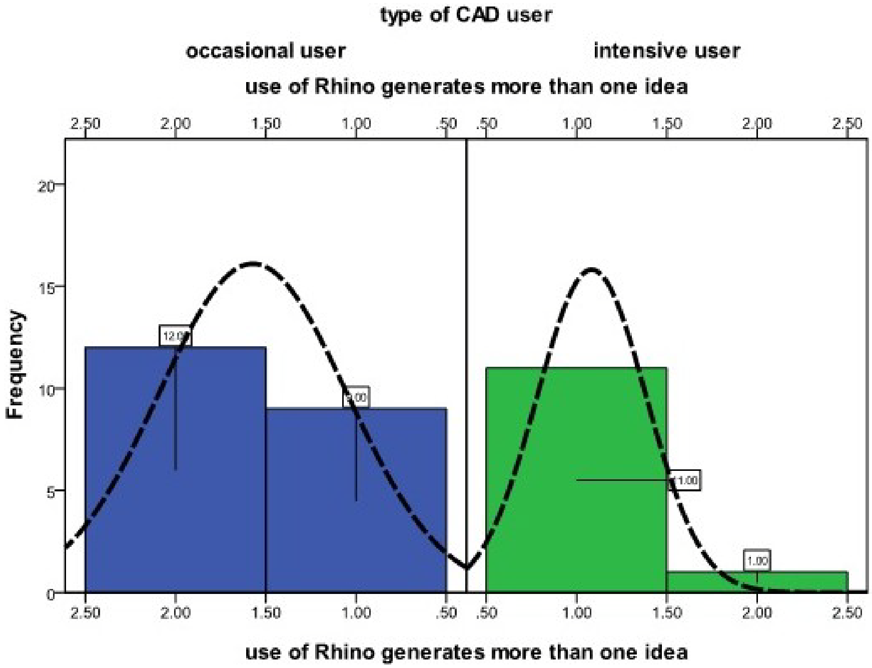

Figure 2 Histogram of user type and volume of design ideas generated

Participant observations showed that intensive users spent an average of 50% of time on design synthesis, 35% on testing ideas and visual appraisal and 15% of time on design analysis. In contrast occasional users spent 54% of their time on analysis, 20% on design synthesis and 26% on testing. Meanwhile the design compositions produced by intensive users were noted as being more complex and more ambitious than those created by occasional users. Almost all intensive users adopted a non linear elliptically based geometry for their designs whereas occasional users opted for simple rectangular forms. At least 9 intensive users were observed attempting very complex and challenging forms and design compositions for the house while only 2 occasional users were observed pursuing complex design compositions. The observation of design compositions revealed that intensive users mainly used sweeping, revolving and lofting mechanisms to create 3D forms, a set of operations which by their own nature are cognitively demanding and complexity orientated. Occasional users, on the other hand, extruded planar profiles vertically in a straight line to create simple geometry with little cognitive load, i.e. the 3D form was almost a literal translation of the plan.

On design synthesis, participant observations showed a big difference between the two groups. On site analysis intensive users generated 3 diagrams on average compared to 1.5 for occasional users. The average number of analytical drawings and diagrams on design synthesis produced by both groups were as follows: orientation and passive solar exploration, 4 by intensive and 1.7 by occasional; light analysis inside, 3 by intensive and 1 by occasional; form, 5 by intensive and 2 by occasional; structure, 2.7 by intensive and 1.1 by occasional; aesthetics, 3 by intensive and 1 by occasional; functional aspects, 5 by intensive and 2 by occasional. Figure 3 exhibits the relationship between the use of CAD and the synthesis process of design concept.

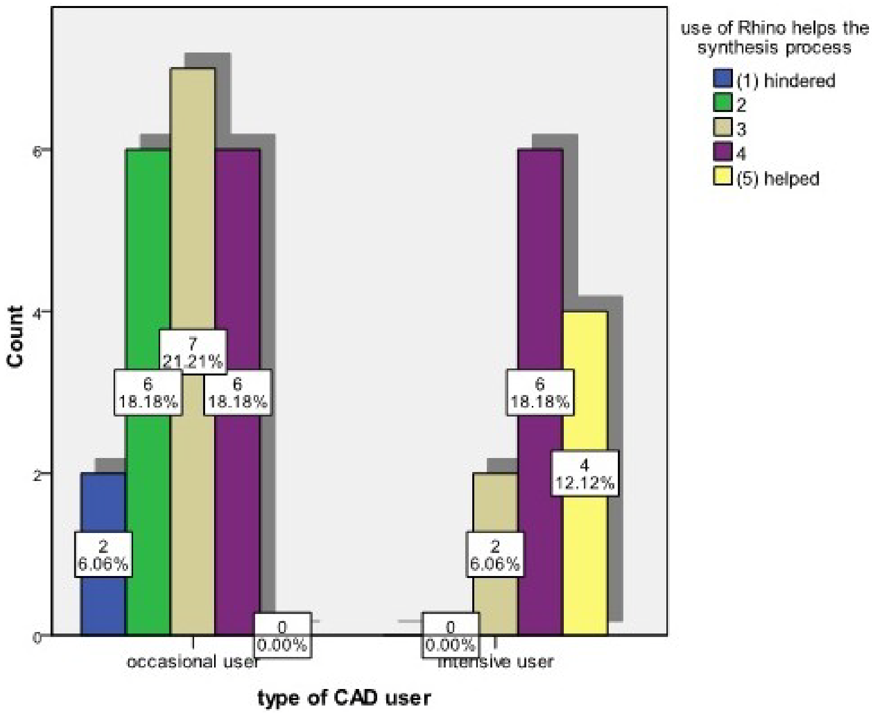

Figure 3 User type and the synthesis process

Ten intensive users scored of 4 and 5- very 'helpful' whereas 6 occasional users of CAD fell within the 4 category. Looking at the sample's overall picture in Figure 3, 18 students, including 6 occasional CAD users, saw an advantage in using CAD for design synthesis- map a form to a context (design problem). Issues of site, orientation, light, sun shadows as well as functional, formal, structural and aesthetics consideration were reported by the interviewed students as being examined, visualised and tested quickly with the aid of CAD. This power of 'dynamic' visualisation, not present in traditional means such as paper-and-pencil, can extend the design process further to materials mapping which creates an exciting visual stimulus for inspiration in creative thinking. Once a material is mapped onto a surface design decisions on the relationship between materials and geometry can finally be made. The non destructive nature of CAD process is worth highlighting where parts of the structural system can be copied and isolated for further investigation without destroying the overall form. Thus both structure and form can be generated quickly and frequently. During this process

sometimes unexpected happy accidents happen that may help creative thinking. During observations, a dialogue between a student and the computer was recorded: 'well, that is an interesting object, I never thought about that kind of form.'
The association between the conception of complexity as a design trait and the synthesis of architectural form can be enhanced by the use of the computer for two reasons. Firstly the use of Boolean operations in CAD can push design to very high levels of complexity. Secondly, this achieved level of complexity can be easily visualised and tested through computer simulation. So in all computers can help designers pursue complexity as a design theme. Again participant observations recorded that on average each member of the intensive group used Boolean operations and surface sweeping 32 times compared to an average of 12 times usage by the occasional group. Also the intensive group used 35% of their time testing whereas the occasional group used 26% of their time on testing. Table 3 represents the correlation between the conception of 'complexity' and each of design 'synthesis and 'evaluation'. In statistics, a correlation between 'two' variables means an association, not necessarily a causation. Students were asked if the use of CAD had helped them in dealing with complex objects.

Table 3 Correlation between the 'synthesis' process, conception of 'complexity' and design evaluation

Correlations

			use of Rhino helps the synthesis process	use of Rhino helps conceive/deal with complexity	use of Rhino helps the evaluation process
Spearman's rho	use of Rhino helps the synthesis process	Correlation Coefficient	**1.000**	**.429****	**.406****
		Sig. (1-tailed)	**.**	**.006**	**.010**
		N	**33**	**33**	**33**
	use of Rhino helps conceive/deal with complexity	Correlation Coefficient	**.429****	**1.000**	**.327***
		Sig. (1-tailed)	**.006**	**.**	**.032**
		N	**33**	**33**	**33**
	use of Rhino helps the evaluation process	Correlation Coefficient	**.406****	**.327***	**1.000**
		Sig. (1-tailed)	**.010**	**.032**	**.**
		N	**33**	**33**	**33**

**. Correlation is significant at the 0.01 level (1-tailed)
*. Correlation is significant at the 0.05 level (1-tailed)

Table 3 displays a significant positive correlation coefficient of 0.327 & significance of 0.032, < 0.05, between the 'evaluation' process and the conception of 'complexity'. Similarly Table 4 shows an even higher correlation coefficient (0.429, significance 0.006, <0.05) between the 'synthesis' process and conception of 'complexity'. This implies that the use of CAD has helped students in both the 'synthesis' and the 'evaluation' process of complex forms. In the interviews, a student intimated 'it helped me conceive my project and draw it. It would have been too hard to deal with such a complex geometry without Rhino'.
The analysis of design projects from intensive CAD users revealed a design tendency toward complex forms rather than simple ones and a pursuit of non linearity and curvy geometry. This can be evidenced by looking at a sample representing the work of 3 students.
The research assumption that students' use of Boolean operations in CAD will help generate fluency and variety in geometrical forms was confirmed in Table 4 which computed the correlation between 'variety' and 'volume' of design ideas.

A correlation coefficient of 0.515 confirmed that both ‘volume’ and ‘variety’ of ideas had increased. From the interviews and the analysis of various stages of student design work on the computer, a mean of 3 design ideas were generated by intensive users compared to a mean of 1.5 by occasional users. The results from this sample suggest that CAD can also assist ‘divergent’ thinking, which is a necessary condition for creative thinking.

Table 4 Correlation between ‘volume’ and ‘variety’ of design ideas

Correlations

			use of Rhino generates variety of design ideas	use of Rhino helps the volume of design ideas
Spearman's rho	use of Rhino generates variety of design ideas	Correlation Coefficient	1.000	.515(**)
		Sig. (1-tailed)	.	.001
		N	33	33
	use of Rhino helps the volume of design ideas	Correlation Coefficient	.515(**)	1.000
		Sig. (1-tailed)	.001	.
		N	33	33

** Correlation is significant at the 0.01 level (1-tailed)

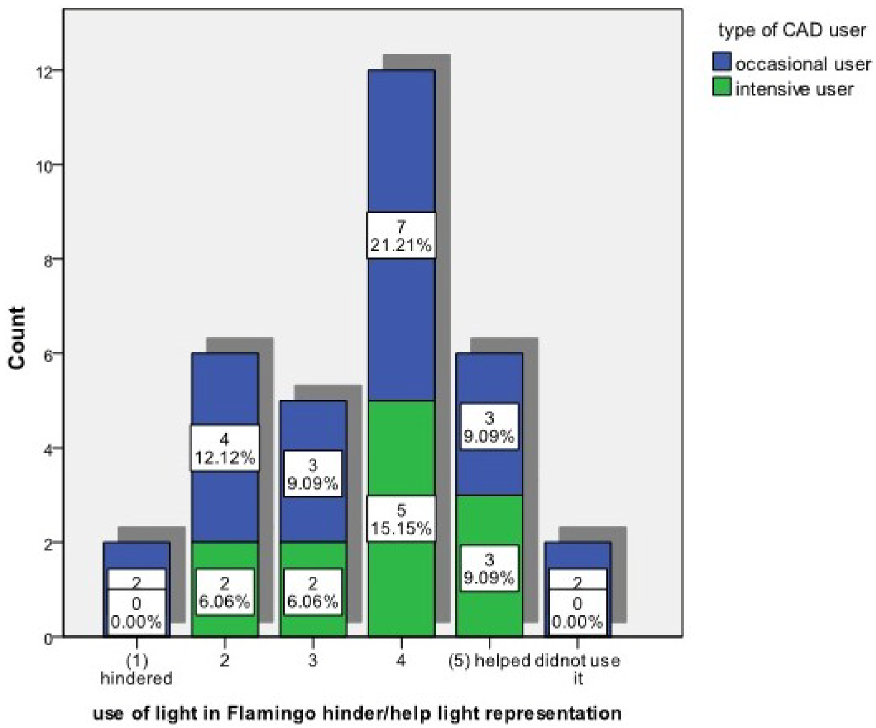

Figure 4 User type and light representation

8.2 Attitudes toward computer aided lighting (CAL)

Traditional media of architectural representation such as paper-and-pencil is weak in representing light in buildings as well as not being able to represent the interaction between light, texture and colour in buildings. Therefore, computers offer a better medium for representing, simulating and analysing light during the design process. In addition, computers’ processing power can account for reflected light between surfaces, adding accuracy and in turn realism to design scenes. Participant observations revealed that on average intensive users performed 13 design activities related to daylight exploration whereas occasional users, on average, carried out 5.4 light related design activities. Students were asked about the influence of using CAD on light analysis, design and representation. These observations were supported by the statistical evidence. Figure 4 shows a big difference between user types. From a total of 12 intensive CAD users, 8 had found it helpful in dealing with light representation compared to 10 occasional users (out of a total of 21) with 2 not using it. Figure 5 shows the mean vote on a series of issues associated with light representation and their impact on the design process. A mean of 3.7 (out of a maximum 5) was registered for the computer helping 'light representation', 3.6 for CAL's impact on the design process and 4.0 for 'adding a sense of realism' to scenes- the visualization process. The traditional working method of model making is more accurate for light simulation in design than paper drawing. In the experiment, students were observed trying various combinations between light and material colourand texture to achieve higher realism.

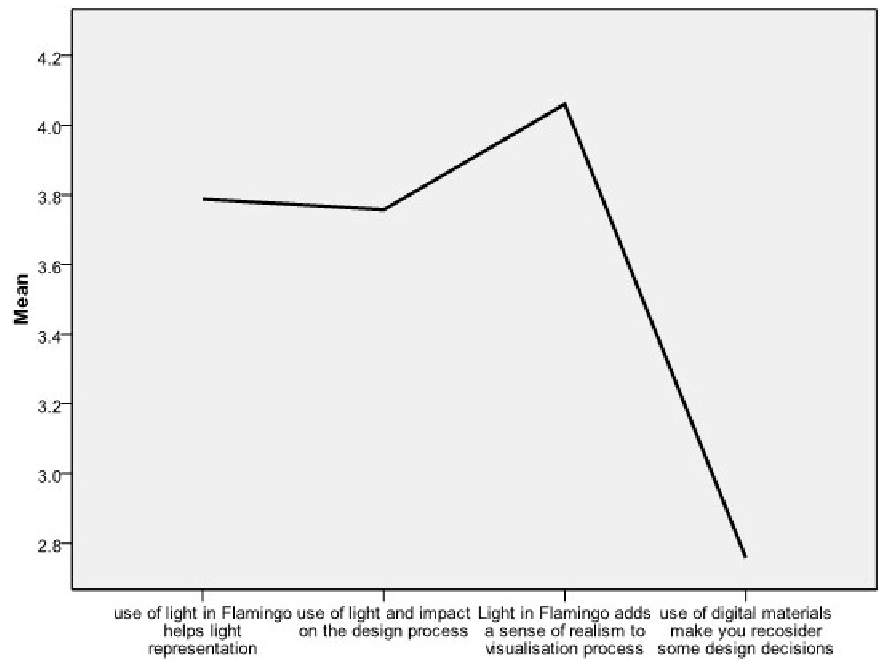

Figure 5 Mean value of light variables

Figure 5 also shows the mean of the variable 'use of digital light made you consider some design decisions' to be around 2.5. This suggests that the response to this variable was evenly distributed on the scale; light was deemed very important by some students but not so important by others to affect a change in design decisions after they were made.

Observations recorded that the intensive group made a total of 27 changes to designs in order to improve daylight inside the house, compared to a total of 26 changes to design affected by the occasional group. Again these observations were confirmed further by the statistics in Table 5, which depicts a significant correlation between the impact of digital light on the 'design process' and to affect a 'change in design decisions' (a computed coefficient of 0.533 and a significance of 0.001, $P < 0.05$).

Table 5 Correlation between digital light and the design process

Correlations

			use of light and impact on the design process	use of digital light made you reconsider some design decisions
Spearman's rho	use of light and impact on the design process	Correlation Coefficient	1.000	.533(**)
		Sig. (1-tailed)	.	.001
		N	33	33
	use of digital light made you reconsider some design decisions	Correlation Coefficient	.533(**)	1.000
		Sig. (1-tailed)	.001	.
		N	33	33

** Correlation is significant at the 0.01 level (1-tailed)

A further two variables on the psychological perception of digital light in the design process, were also examined in Table 6. It confirms a significant correlation (0.549) between two dimensions: the computer as a device that helps 'light representation' and adds 'sense of realism' to the visualization process. This implies that the computer can help reduce the perceived gap between 'representation' and 'reality'.

Table 6 Correlation between digital light representation and visualisation

Correlations

			use of light in Flamingo hinder/help light representation	Light in Flamingo adds a sense of realism to visualisation process
Spearman's rho	use of light in Flamingo hinder/help light representation	Correlation Coefficient	1.000	.549(**)
		Sig. (1-tailed)	.	.000
		N	33	33
	Light in Flamingo adds a sense of realism to visualisation process	Correlation Coefficient	.549(**)	1.000
		Sig. (1-tailed)	.000	.
		N	33	33

** Correlation is significant at the 0.01 level (1-tailed)

8.3 Attitudes toward the concept of digitally processed materials

With reference to the representation of materials within the design process, computers offer significant advantages over conventional media of paper-and-pencil in terms of speed of simulation and accessibility to material libraries. The accurate simulation of interaction between light and materials as the latter are being mapped to geometry makes CAD an excellent medium for design experimentation. However, the lack of physicality in digital materials makes their perception somehow problematic when compared to real materials. The notion of 'problematic' perception is supported by the statistics in Figure 6 where 27 students reported a significant difference in their perception of materials between physical and digital worlds. Nine intensive CAD users and 18 occasional users scored 3 and above. A possible interpretation could be that unlike physical materials, digital materials look pristine and unblemished. Also 'ageing' in materials is not properly represented within digital databases. Seven interviewees used the word 'weird' to describe the lack of 'physicality' in digital materials; 'our perception is somehow distorted; we experience (material) textures through the sense of 'touch', which adds significantly to the overall dimension of human perception and experience, is lost here'.

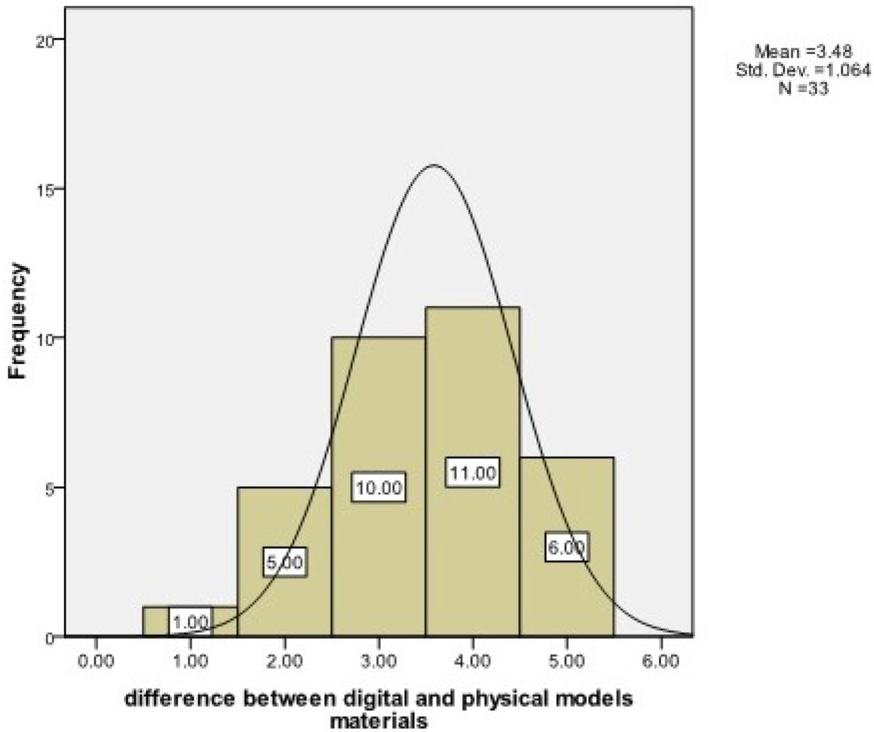

Figure 6 User type and material perception

Participant observations confirmed that on average each intensive user applied 4 different types of materials to their design and accordingly made on average 2 changes to their design. A similar frequency of experimentation with materials was also observed in the occasional group; frequencies of access to and use of material libraries was 3.6 with an average of 1.8 changes to design. Figure 7, all 12 intensive users intimated that applying digital materials had a positive impact on the design process- 'made it more interesting'. Occasional users followed a similar line of thought in their response to the same issue with 19 users scored 3, 4 and 5 (mean=4). The ANOVA test used, did not compute a significant difference (in variance) between the 2 groups, Significance =0.258, $P > 0.05$. When interviewed an excited subject hinted that mapping digital materials onto surfaces and objects enabled experimentation and exploration of different materials and their appropriateness for a specific geometry and context. Another stated 'the appearance of materials changes under different lighting conditions'.

Observations also revealed an important distinction between realism in design and realism in built form. It appears that when student were designing with the computer the notion of 'realism' was completely 'perceptual', i.e. a property of the mind, rather than 'experiential' which is dominated by sense organs. Figure 8 illustrates a 'box plot' to examine the 'mode' statistics as a measure for central tendency. For data that varies widely, mode statistics is more representative than the mean. For the variable 'perceived difference between digital and physical materials', the response grouped mostly around the '4 mode'- the range stretched below 3 with one outlier (student 15) with 1. For the variable 'digital materials add a sense of realism' the response clustered around a mode of 4. It could be that the perception of 'digital materials adding a sense of realism' appears to follow a common pattern amongst both intensive and occasional users, whereas the 'difference between digital and physical materials' seems to generate a 'reaction' response by some users.

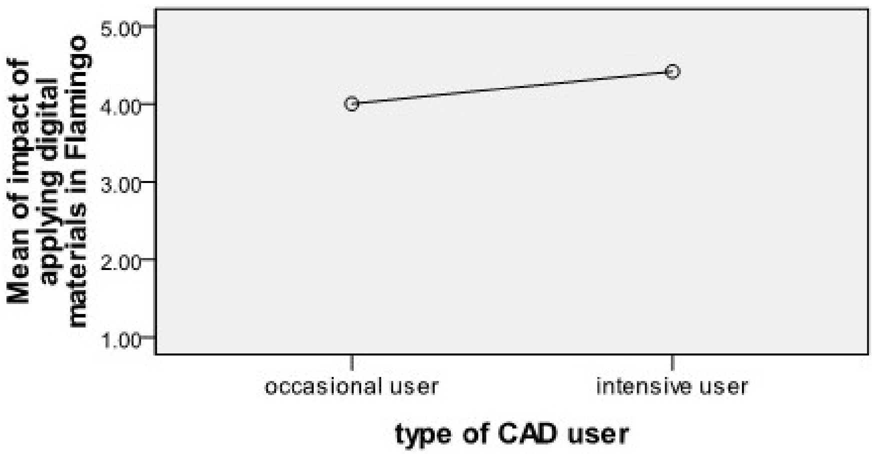

Figure 7 Impact of applying materials by user type

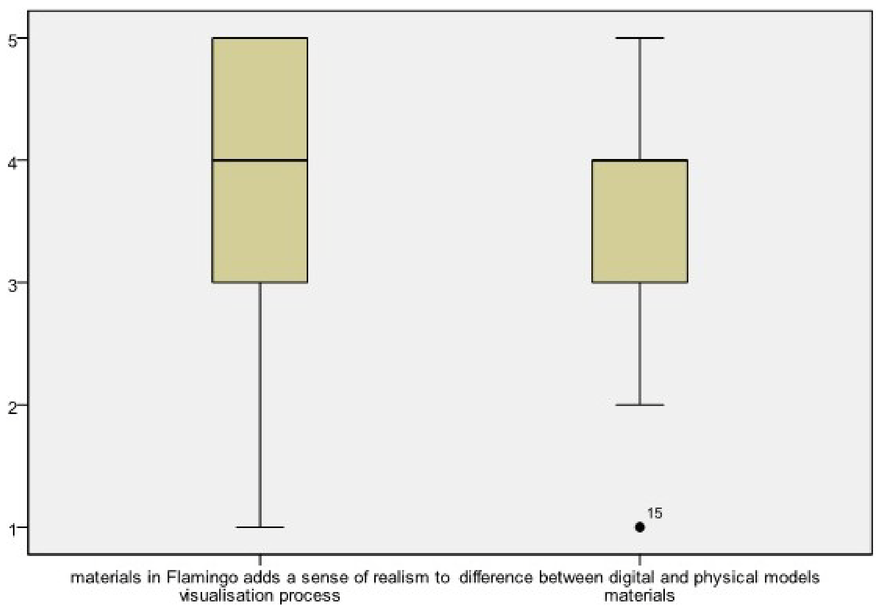

Figure 8 Box plot for mode statistics

Participant observations confirmed that there was an association between the average number of digital materials used, counted by the author as 4, and the number of average changes to design, counted as 2. The statistics confirmed this association in Tables 7 and 8, which display the correlation between the application of digital materials and the variables: ‘representation’ and design ‘decision making’ process. A correlation coefficient of 0.365 with a significance of 0.018 (< 0.05) was computed between digital light and representation; students felt that the use of digital materials helped the phenomenon of architectural representation. The correlation between the ‘impact of applying digital materials’ on affecting ‘a change in design decisions’ was even stronger, a coefficient of 0.447 and a significance of 0.005 ($P < 0.05$). This suggests some students did in fact change their designs after applying digital materials. Further research is needed to determine the nature of changes, i.e. formal, spatial or aesthetics.

Table 7 Correlation between the impact of using digital light and representation

Correlations

			impact of applying digital materials in Flamingo	use of light in Flamingo hinder/help light representation
Spearman's rho	impact of applying digital materials in Flamingo	Correlation Coefficient	1.000	.365(*)
		Sig. (1-tailed)	.	.018
		N	33	33
	use of light in Flamingo hinder/help light representation	Correlation Coefficient	.365(*)	1.000
		Sig. (1-tailed)	.018	.
		N	33	33

* Correlation is significant at the 0.05 level (1-tailed)

Table 8 Correlation between the impact of using digital materials and decision making

Correlations

			impact of applying digital materials in Flamingo	use of digital materials make you reconsider some design decisions
Spearman's rho	impact of applying digital materials in Flamingo	Correlation Coefficient	1.000	.447(**)
		Sig. (1-tailed)	.	.005
		N	33	33
	use of digital materials make you reconsider some design decisions	Correlation Coefficient	.447(**)	1.000
		Sig. (1-tailed)	.005	.
		N	33	33

** Correlation is significant at the 0.01 level (1-tailed)

8.4 Attitudes toward digital presentation

The traditional design studio has two important ingredients: the critique and project presentations on paper. Digital presentations on the computer are gradually being accepted in design studios and are becoming the norm for client presentations in practice. The argument in support of digital presentation seems to be multi dimensional. The luminosity of drawings on the screen, the legibility of drawing from a distance, the ability to navigate around the design in three dimensions, are just few advantages. The latter point makes describing design schemes easier as one can instantly visualize any part of the design scheme which needs to be looked at without the need for redrawing. In the computer three dimensional designs can be viewed from any angle whereas on paper they can only be seen from one angle, the drawn axonometric angle. This makes design narratives more coherent and quicker. When intensive and occasional students were asked about the difference between digital and conventional presentations in design narrative times, the intensive group confirmed that on average digital presentations are shorter by 5 minutes. The occasional group suggested a 4 minute difference on average between both presentation modes, with the digital being the shorter of the two. Figure 9 confirms that 10 out of 12 intensive users of CAD responded positively that digital presentation in power-point helped design narrative, providing a linear structure for the argument and making design descriptors more accurate. Eighteen out of 21 occasional users showed a similar response. Evidence from observations suggests students used precise design descriptors and were more confident in explaining their design decisions to peers. Somehow, being able to visualize the project in three dimensions, navigating around the form from every possible angle as well as going forward and backward through the scheme generally made them more confident about what they were doing and what they have achieved.

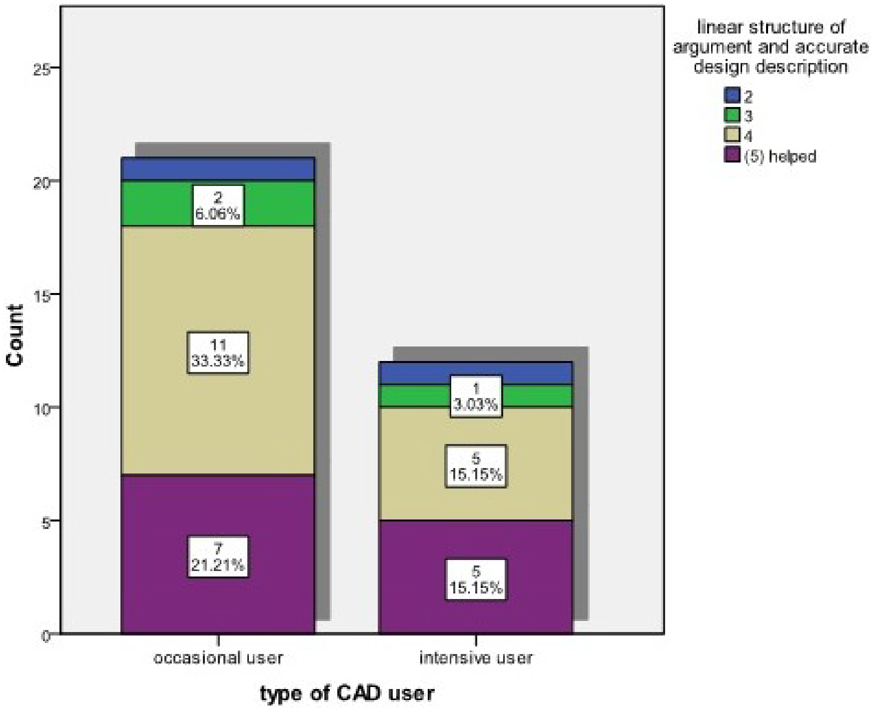

Figure 9 User type and digital presentation

Participant observations of student narratives of design project on the computer did not reveal any problems of speech stutter or nervousness, both associated with low levels of perceived confidence. Table 9 tested issues on digital presentation- a correlation coefficient of 0.314, a significance of 0.038, $P<0.05$, was computed between the influence of using digital presentations on: levels of confidence while describing the project and the structure of design argument.

Observations also revealed that the use of digital presentations has affected intensive users' attitudes towards the design process. Nine intensive users were observed to modify their design process from 'analysis-synthesis-evaluation' to 'analysis-synthesis-presentation-evaluation-representation'. Figure 10 shows that 9 out of 12 intensive CAD users felt that the use of digital presentation made a big influence on the design process. Some students intimated that digital presentations allowed them to experiment with composition, colour of text and context background and compliment presentations with animations and sound. The inclusion of sound and animations makes presentations more dynamic and also has the advantage of engaging other senses. Seventeen out of 21 occasional users of CAD also concurred that digital presentations have influenced their design process.

Table 9 Correlation between digital presentations in power-point and project narrative

Correlations

			the influence of using power-point on confidence when describing scheme	linear structure of argument and accurate design description
Spearman's rho	the influence of using power-point on confidence when describing scheme	Correlation Coefficient	1.000	.314(*)
		Sig. (1-tailed)	.	.038
		N	33	33
	linear structure of argument and accurate design description	Correlation Coefficient	.314(*)	1.000
		Sig. (1-tailed)	.038	.
		N	33	33
	use of digital light make you reconsider some design decisions	Correlation Coefficient	.165	.231
		Sig. (1-tailed)	.180	.098
		N	33	33

* Correlation is significant at the 0.05 level (1-tailed)

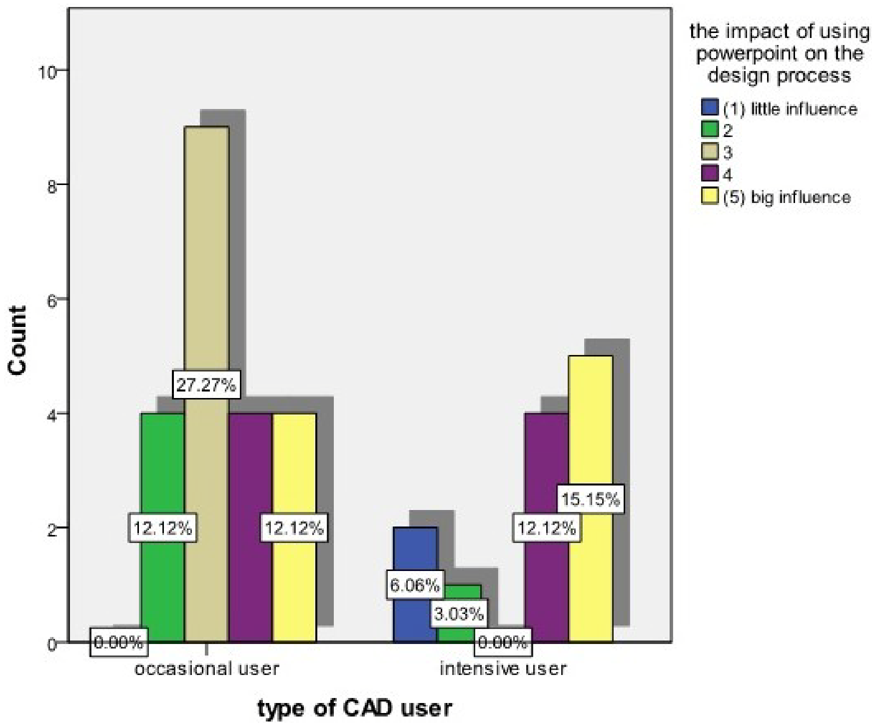

Figure 10 User type, power-point and the design process

9 Conclusions

The conclusions drawn from this investigation have to be viewed with care due to limitations on sample size as the study was limited to 12 intensive and 21 occasional CAD users. In addition a single case study with a limited number of variables can at best refine a theoretical proposition rather than invent a new one. For more objectivity and validity a larger sample is needed and also a control group to compare samples for any 'placebo' effect. However, the study conducted an in depth participant observation activity where students' design behaviour was monitored and a significant number of design moves were counted and analysed. These observations were used as a measure to crosscheck the validity of statistical analysis.

However, based on participant observations and the statistical figures overleaf, the following conclusions are reached.

There appears to be a relationship between the intensive use of CAD, intended to increase creativity levels in architectural design problem solving and the measured level of creativity in intensive users' response. This was supported both by participant observations and statistical analysis of responses as there was an observed clear difference between 'intensive' and 'occasional' users of CAD in attitudes towards: creativity; digital light; digital materials; digital presentation. Therefore the research rejects the Null hypothesis ONE of no statistical difference.

Participant observations revealed that intensive users explored and engaged with more complex designs than occasional users. Consequently a higher cognitive load can be associated with intensive users. This was evidenced by the unusual curvy forms and geometry seen in the designs of intensive computer users. These types of forms are usually referred to as 'complex' or 'organic'. If the pursuit of complexity is an indicator of creativity, then clearly the computer was seen, by at least the intensive users of CAD, as a useful device for conceiving and visualising complex designs. On judging the design output of intensive CAD users, of which a sample is presented here, it seems that the use of the computer somehow encouraged student to pursue solutions that encompassed complex, non linear and curvy organic geometry. Also it appears that the intensive group paid more attention to the 'form' of the building than to functional aspects.

Computer screen observations by the author confirmed that intensive users used certain CAD techniques including Boolean operations as an effective mean for generating ideation 'variety' and 'fluency', two measures of creativity. Intensive users realised very quickly the potential of the software and generated 3 ideas on average compared to occasional users who created an average of 1.5 ideas. Intensive users then used the software again to change the 3 ideas to create a variety between them before finally settling for a single idea to pursue further in the design scheme.

There was an observed difference in the number of drawings and analysis diagrams between intensive and occasional users, with intensive users producing a greater number of diagrams. Digital materials, light and sun studies were viewed as necessary for design experimentation and exploration, especially in the areas of environmental control and site analysis. Participant observations and correlation results, Table 8, suggest some students did in fact change their designs after applying digital materials. Therefore the Null Hypothesis TWO should also be rejected. The power of 3D visualisation in CAD enabled students, particularly intensive users to 'instantly' see the consequences of their design decisions in the areas of structures, construction and context analysis.

Design narratives were observed to improve with the use of digital presentations. Digital presentations were found to have a positive impact on design narration as far as accurate verbalisation of design and shorter presentation times compared to conventional presentations on paper. Issues of screen luminosity making line drawings appear more interesting, environments made dynamic with animation and sound are areas which were highlighted and thus require further investigation.

If the results from this study is anything to go by then there are clear implications on two levels: design reasoning regarding cognition and design education. It is obvious that the cognitive load in design can be increased and students can be encouraged to pursue complex designs with the aid of CAD software. The fear of pursuing complex geometry, because of the inability to conceive, visualise, test and draw can be dispelled when using powerful CAD programmes. Complex geometry which is elliptical in nature can be constructed and tested easily with the use of CAD. So if the pursuits of complexity and ideation fluency, i.e. volume of design ideas generated, are indicators for creativity then clearly students' creativity was enhanced rather than being inhibited by the use of the computer.

It is obvious, from this experiment, the way design problems are framed and presented through digital media will have a big influence on the nature of design solutions, both in education and practice. In other words, the type of media one works with will eventually determine the nature of one's design output. For intensive users, the change in design behaviour, caused largely by the computer's processing power of turning 2D symbols into complex 3D objects, has manifested itself in two ways: a trait for complexity and ideation fluency, and in turn creativity, and the dematerialisation of complexity- creating complex objects without due consideration to the physicality, gravity and mass of materials.

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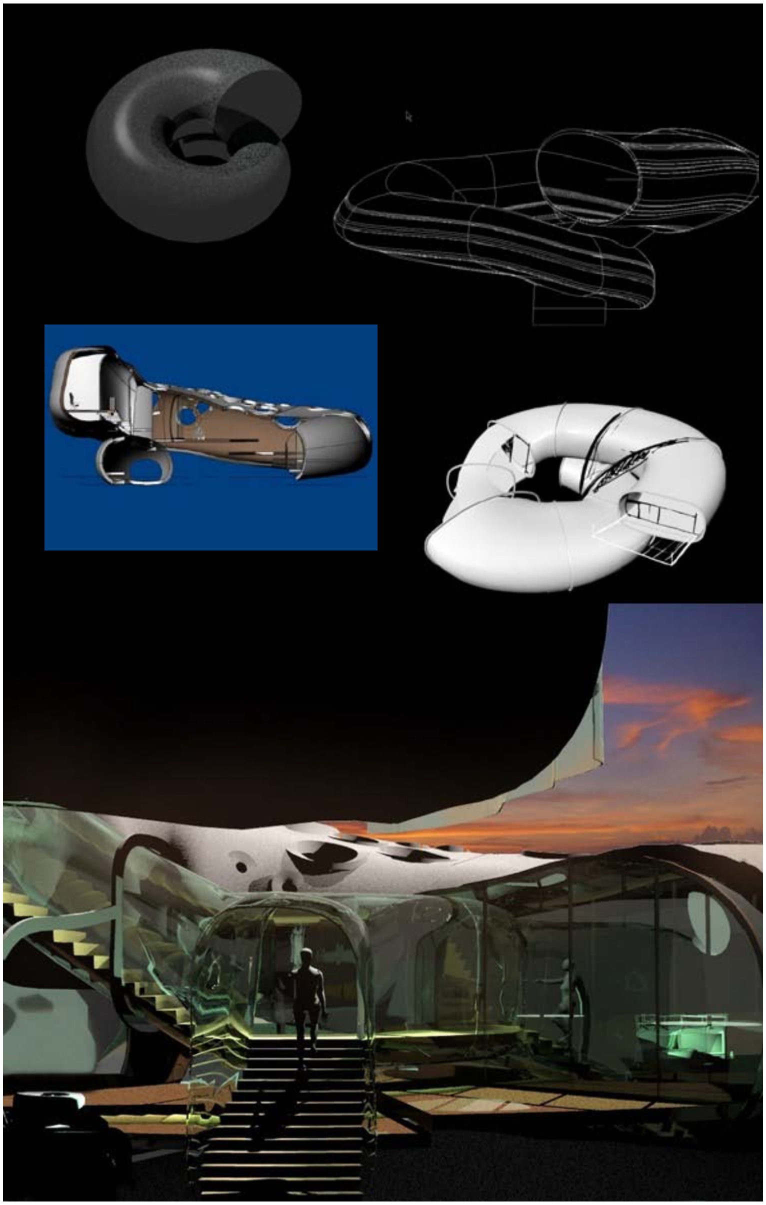
Appendix: Output Analysis

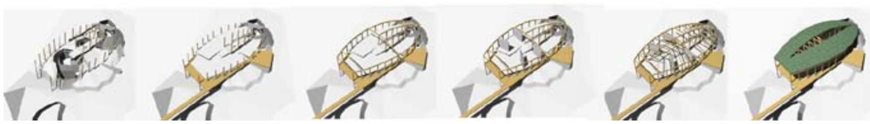
Student A
Located his house next to a natural inlet. His clients were keen on water sports and wanted to maximise on both the physical and visual connection with the sea. The house was considered as an object that had been washed up on the beach, with a materiality and form different to its surroundings. It spiralled up from the rock to allow a four-wheel drive to be parked underneath it as another 'foreign', object. All the outside spaces connected with the house were contained within the spiral so as to leave the ground as natural as possible. The form was adjusted until the living space, which was the termination of the spiral, was aligned to face the sea to the west.



Form exploration, the assembly process, sectional and light study

Student B

Introduced his house as a complement to the coastal setting. It was place on top of a rocky outcrop, where inland cliffs came to a point and met the sea. The promontory was chosen because of its excellent panoramic views. A courtyard typology was explored to create a natural, rocky, concealed outside space. The house was linked by a 'pier' to a Jacuzzi, which in turn was linked to a natural plunge pool in the rocks. The house was shaped to work with the landform and adjustments made to reduce its visual impact. In its final form the proposal mimicked the headland and its existing projecting pier.



Study of space, material, sunlight penetration and connection to seascape and structural sequence

Student C

Wanted to make the most of the site and the views of the sea, while resolving the privacy issues of a site with public access round all its boundaries. His ambition was to create a passive solar house with an outside space, protected from the prevailing winds, which had a direct visual connection with the harbour. He tested and modified the roof form and transparency of his proposal to allow solar penetration into the outside space to the north of the building. He also explored the bigger compositional issues of how to end a row of buildings with a detached house.

Daylight study of outside space testing sunlight penetration, study of proposed house in relation to the existing built context, construction sequence, study of form and material

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