An inquiry into computers in design: attitudes before—attitudes after

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This paper reports on the findings of an empirical investigation into the use of the computer as the only design medium. A group of students took part in an experiment to design a studio for a graphic designer on the computer. Student attitudes towards the design process were assessed at two conditions: before using the computer and after using the computer. Prior to the experiment a literature search was carried out to explore some widely researched design issues such as sketching, design creativity, and computer-aided design. Consequently a number of design variables were identified, developed and then empirically tested. Data collection methods included questionnaires and observations. Statistical analysis of the responses confirms that using the computer has produced a statistically significant difference in attitudes to the design process variables. © 2001 Elsevier Science Ltd. All rights reserved

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New technologies, particularly those related to visual communication, have always had an impact on design representation and the design process. Computers—computer-aided design (CAD)—have been at the forefront of such technologies. However, despite what these technological changes offer in terms of opportunities as well as exciting intellectual challenges, their impact on the architectural design process has not been fully investigated through active research experimentation using classical research models. Recent conferences on computer-aided architectural design (CAAD)1–3 have produced a large number of papers that deal with various aspects of CAAD and the design process, most of which are theoretical and/or descriptive in their research approach. Few studies of an empirical nature—driven by statistically tested hypotheses—have been reported in these conferences and in the wider literature.

The debate about CAAD’s impact on the architectural design process has...
always revolved around the fundamental issue of whether CAAD is a design or a drafting tool. The difference in opinion is still there: between those who focus only on the ‘conceptual’ phase of the architectural design process, and see existing CAAD tools as merely drafting rather than design tools, and those who take a broader view of the design process and acknowledge the impact of CAAD on areas of drafting, visualisation, three-dimensional (3D) modelling and performance analysis, all of which are seen as part of the design process and as important as the ‘conceptual’ phase. However, recent developments in regard to both the 3D modelling capabilities of CAD software and the theoretical foundation of CAD imply that CAD is adapting to the needs of the design process, thus increasing its chances of being used as a design tool at an early stage of design. The emergence of new CAD tools such as Rhinoceros, a NURBS (non-uniform rational B-splines) modeller, means that 3D free-form organic surfaces and solids can be created intuitively and quickly at the early design stage, a serious limitation of the traditional polygon modellers. Also, recent works on ‘genetic programming’ may lead to the possible development of a new breed of ‘evolutionary’ CAD tools that can help designs to evolve from scratch. For example, GADES—a genetic algorithm designer developed by Bentley—was used to evolve various designs successfully from coffee tables to hospital layouts. According to Bentley, evolutionary CAD tools ‘allow the designer to explore numerous creative solutions to problems, overcoming design fixation or limitation of conventional wisdom by generating these alternative solutions for the designer’. Also Karl Sim’s computer graphics program, used by many visual artists, uses genetic algorithms (GAs) to create new images from pre-existing images. However, the limitation of GAs is that the evaluation criteria upon which ‘second-generation’ solutions are generated from ‘first-generation’ are purely functional rather than functional and aesthetic. Although GA, as a design technique, is impressive, it cannot make computers autonomous, and improve their design skills to a level that matches the human brain. So one has always to bear in mind these limitations when looking at CAAD’s nature and its integration with the design process.

Moreover, if CAAD is to achieve ‘fusion’—rather than integration—with architectural design, its knowledge-based domain has to relate/adapt more to architectural design theory, and also influence the development of its rapidly growing skill-based domain—of tools. For example, compared with design, CAAD is lacking in both definition and structure. Design has many definitions, with varied emphasis, that can be cited in the literature. Areas of emphasis include: logical data processing and analysis methods; control and management of complexity; optimum image to be reached through iteration; ‘constraints’ imposed by the environment of the problem;
intention of embodiment as hardware. In contrast CAAD has fewer definitions. Furthermore, the conventional design process has a well established formal structure of analysis–synthesis–evaluation–presentation, whereas the computerised design process has no such established structure. Mitchell offers a limited structure by viewing CAAD as a ‘special kind of problem solving process’ that searches among alternatives for an optimum solution according to a criterion. New models of the design process that encompass CAAD, or are compatible with CAAD, need to be developed.

1 Design and creativity

In some design definitions, explicit reference has been made to concepts of creativity, originality and intuition. Zeisel argues that the process of designing embodies so many intangible elements such as creativity, intuition and imagination which are essential to design quality. Originality in design is also referred to by Archer.

Regarding creativity, it is still clearly a mysterious and largely unknown process. Two authors, Koestler and Storr, have studied creativity from two different perspectives. Koestler focused on the ‘how’ of creation whereas Storr was concerned with the ‘why’ of creation. In his treatise *The act of creation*, Koestler uses a diagram of two planes to explain the difference between ‘routine’ and ‘creative’ skills of thinking. He argues that routine thinking operates on a single plane—or context, while the creative act always operates on more than one plane, the ‘bisociation of two mutually incompatible contexts’. Thus creative thinking, according to Koestler, can be attained by linking ideas from two different contexts. Storr, on the other hand, accepts that creativity is the ability to bring something new into existence, and on ‘why’ we create, he suggests that creativity is a ‘biologically-adaptive’ process that enables us to ‘gain mastery over the external world’ and to ‘assert our own identity’.

Puzzling and mysterious as it might be, one could claim that creative thinking is a product of past experience and knowledge as well as presumably an inherent talent. Therefore, if one is not dealing with mediocrity, it is reasonable to conclude that the greater the knowledge and experience, the greater will be the possibility of a creative leap. This implies that expert designers, or masters, would solve design problems better—or in a more creative manner—than beginners because of their superior knowledge and experience. In addition experts think in ‘chunks’—larger ‘blocks’ of information which already contain the smaller ‘sub-blocks’. This makes the thinking process more efficient as the smaller blocks, already contained in the chunks, require no further thought.

A literature review on creativity in ‘general’ (as a thinking skill) and crea-
Creativity in ‘design’ revealed that in both contexts the ‘irrational’ thought rather than the ‘rational’ is the sufficient condition for creativity to happen. Koestler suggests that ‘we are at our most creative when our rational thought is suspended’\textsuperscript{15}. Storr also maintains that ‘summoning’ the irrational leads to the discovery of a creative solution to the problem\textsuperscript{17}. Similarly, the architect Aalto, in describing his problem-solving techniques, argues that architectural design problems form a ‘complex tangle’ of social, psychological, economic and technical demands which ‘cannot be unravelled in a rational or mechanical way’\textsuperscript{20}. He goes on to say ‘I forget the entire mass of problems for a while. I then move on to a method of working which is very much like abstract art. I just draw by instinct, not architectural synthesis, but what are sometimes childlike composition…, and on this abstract basis the main idea gradually takes shape’. It appears that there were two distinctive processes at work: ‘rational’ (architectural synthesis) and ‘irrational’ (childlike composition), and the idea emerged after Aalto restrained the ‘rational’. However, one could argue that the choice of ‘which’ mode of thinking to suppress depends on the architect himself and his design approach (functional/aesthetic).

Creativity in design has not been only examined in relation to problem-solving—e.g., the process—but also to aspects of personality such as ‘independence’. In a study, architects were divided into three groups based on their level of creativity, and their concerns were examined. It was found that the concerns of the most creative group were focused around meeting an internal ‘artistic standard of excellence’ whereas the concerns of the least creative group were mainly to do with conforming to general standards of the architectural profession\textsuperscript{21}. Another study found that creative artists tend to have a preference for ‘complexity’, ‘asymmetry’ and ‘incompleteness’\textsuperscript{22}. In conclusion, to understand the holistic nature of creativity in design one has to look beyond the ‘process’ of creativity in design, to the psychological aspects of ‘personality’ of creative architects and designers.

Associated with creativity is ‘intuition’, another mode of thinking which, unlike creativity, is closely linked to duration. For example, Bergson suggests ‘to think intuitively is to think in duration’, and ‘intuition is arduous and cannot last’\textsuperscript{23}. This means that the idea which emerges out of intuition usually starts by being ‘obscure’ or abstract. If creativity in design happens in small creative steps, like small explosions, rather than all in one big bang, then intuitive thinking has to play some role in, if not is largely responsible for, the initiation of these small creative leaps.
2 Design research

While definitions for both design and the design process existed in the literature, very few definitions for ‘design research’ were found after several searches. Design research, one could argue, is a systematic inquiry that creates knowledge on various aspects of design and the design process. Design investigations can be categorised under four headings: studies on ‘tools’; studies on ‘processes’; research on ‘ mediums’; research on method.

2.1 Studies on ‘tools’—conventional sketching

This type of study deals with the role of sketching in crystallising design notions and forming ideas at the early design stage. The foundation for this research area were laid down by the pioneering work of Rudolf Arnheim, from Harvard, whose publications are being used as textbooks by artists, designers and art psychologists. In Visual thinking Arnheim asserts that the separation between seeing/perceiving and thinking/reasoning is unreal and misleading24. In New essays on the psychology of art, Arnheim, through the works of three art psychologists, explores the mechanisms of art perception and cognition and its relevance to Gestalt Psychology25. In Art and visual perception, he warns against art being drowned by talk, and remarked that ‘visual things cannot be expressed in words’ and ‘verbal analysis will paralyse intuitive creation and comprehension’26.

Investigators of sketching such as Goldschmidt link ‘visual perception’ to architectural drawing via sketching, thus introducing a further dimension to Arnheim’s two dimensions (of the eye and the brain). The resultant relationship between the activities involved in sketching reads: active sketching (hand)→passive perception (eye)→active cognition (brain). She uses terms such as ‘figural conceptualisation’ to reiterate her rejection of any dichotomy between the design ‘concept’ and the ‘figure’—sketch27.

Recent works by Lawson28, Fraser and Henmi29 and Robbins30 on the role of drawing in architecture claim that despite the use of CAD for the manipulating and editing of drawings and for creating photo-realistic images, animation and walk-through, conventional drawing methods are still preferred for creative design and design development. However, these claims need to be verified empirically.

The uniqueness of sketching as a design tool is one way of looking at the design/tool relationship. Other design-aiding media include the use of physical models, and CAD packages which after all incorporate some form of sketching. Recent work on the Electronic Cocktail Napkin, ‘an experimental computer-based environment for sketching and diagramming in...
conceptual design’\textsuperscript{31}, is evidence that CAD programs can be written in ways to make them useful for sketching and creative design. This software is a ‘shape based reminding programme’ that employs hand-drawn sketches or keywords to index and access visual databases. However, despite the existence of a few individual experiments on computer-aided sketching, they have made little impact on the development of commercial CAD packages, most of which continue to retain very basic and under-developed sketching routines.

From the above literature, it is obvious that sketching plays an extremely important role in the design process and computer-aided sketching, though in its infancy, is still possible. However, there is a need for empirical research to investigate how design with the computer is possible where sketching ability is hindered rather than facilitated. It is also important to identify the changes to the nature and structure of the design process that need to be made if CAD is to be used as a design tool.

2.2 Studies on cognitive ‘processes’: measuring the design behaviour

This group of studies attempts to investigate the design process by recording the designer’s behaviour and his spoken thoughts using several techniques, one of which is the ‘protocol’ analysis. Introduced by Newell and Simon\textsuperscript{32}, and adopted by many investigators, protocol analysis involves setting up quasi-laboratory experiments to record the behaviour of the designer using video-tape (Delft–XeroxPARC workshops, Akin and Lin)\textsuperscript{33}, audio-tape (MIT Branch Library Design)\textsuperscript{34}, sketches on paper, etc. The objective of studies like Akin and Lin’s is to understand the intuitive process in design, using concepts and tools from cognitive psychology, and predict how architects design\textsuperscript{33}.

More detailed studies of the cognitive strategies involved in architectural design have been reported in the literature. For instance, Lawson compared the performance of fifth-year architecture students and fifth-year science students in solving a design-oriented problem\textsuperscript{35}. An on-line computer program, capable of solving the problems, ran and monitored the experiment and compared the subjects’ solutions with the computer-generated optimal solution. Statistical analysis of subjects’ protocols revealed that most science students adopted a ‘problem focusing strategy’ whereas most architecture students operated a ‘solution focusing strategy’.

2.3 Research on media: computer-aided design (CAD)

The theoretical foundations of CAAD as a subject were laid down by Mitchell in his treatise on CAAD\textsuperscript{14}. The origins of the theory behind CAD

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35 Lawson, B ‘Cognitive strategies in architectural design’ Ergonomics Vol 22 No 1 (1979) pp 59–68
was traced back to Aristotle’s concept of a generative system that can provide a variety of potential solutions to a problem. Generative systems have been utilised in philosophy, literary composition, musical composition, engineering design and architectural design. Generative systems were systematically used by Lenardo da Vinci for the generation of central plan churches, and by Durand for the creation of plans, elevation and urban forms from different combinations of building elements (columns, walls, etc.). Classical architecture was also based on having a fixed vocabulary of architectural elements that can be assembled in different combinations to generate architectural forms. A modern application of this principle, which integrates CAAD and architectural design theory, can be found in Stiny’s work on ‘shape grammar’ (generation of shapes according to relational rules—grammar). However, this type of ‘innovative’ research remained confined to the boundaries of academia and by implication made little impact on the development of high-end CAAD programs.

Almost all high-end CAAD programs have improved markedly, and they now offer some form of lighting, colour/materials and texture maps that enable the creation of photo-realistic images more easily and more frequently during the design process than by hand. The ‘performance–analysis’ area of CAAD has also made significant progress and now offers applications for visual modelling of the acoustic behaviour of sound waves within enclosures, and the visual simulation of air movement using Computational Fluid Dynamics programs, which are fascinating areas for design experimentation and appraisal.

Conferences on CAAD like ECAADE and CAADRIA continue to run annually with varied focus on specific CAAD themes each year.

The notion that computers can be employed in an innovative way in architectural practices has been reported in the literature. LeCuyer compared two different approaches to the creative use of computers in design by two world-class architects. She remarked that ‘while Gehry employs computers in design development, Eisenman uses computer-generated forms as his starting point’. Yet both Eisenman and Gehry are very experienced designers, and with their great knowledge and experience, they may find it not so challenging to adapt their working methods to fit CAAD and at the same time create buildings of elegant form and design. Novice designers might find it extremely difficult to adapt their design methods in relation to CAAD and at the same time produce ‘good’ designs.
2.4 Research on design methods
This type of research is concerned with the structure of the ‘design process’ and the philosophy of the ‘design method’. It has attracted a great deal of attention from research scholars which led, during the 1960s and the 1970s, to the emergence of special research groups such as the ‘Design Methods Group’ in the USA and the ‘Design Research Society’ in the UK. The seminal work of Cross on design methodology is one of the most significant ones in this area\textsuperscript{40}. Developments in design methodology and process have resulted in a number of design models which differ in structure but agree that the design process, more or less, consists of: analytical phase—inductive reasoning; creative phase—design hypothesis via deductive reasoning; executive phase—visual reasoning/communication.

3 Design brief: a studio for a graphic designer
In order to examine further some of the issues highlighted by the literature, this research conducted a design experiment using a CAD program as the sole design medium. Students were asked to design a studio in a garden site for a graphic designer according to the following design brief:

(1) The studio is to have its own entrance so clients can gain access directly from the street and all necessary servicing must be made independently. At the same time access is to be provided through the garden from the house although it is not necessary for this link to be enclosed. A separate outside space is to be created as part of the new workplace.

(2) The studio must be designed to accommodate client meetings, the production of graphic work, general administration and a small display of finished work. The computer, VDU and printer, photographic stand, darkroom equipment, layout space, phone and fax are the graphic designer’s most frequently used equipment and copious storage space is essential. A toilet and wash hand basin are also required, together with general storage for coats and cleaning equipment. The total floor area of up to 40 square metres maximum is to be provided.

(3) Both natural and artificial light must be considered to create a pleasant working environment and some thought should be given to the way in which the studio will be heated and ventilated, as both issues will influence the form of the design proposal, the size and location of openings and the nature of heating and ventilating equipment.

3.1 The design process
On the first day the authors—a lecturer in CAAD and a design studio tutor—introduced the research project to 30 second-year architecture students of the Mackintosh school, all of whom had expressed a strong interest and desire to participate voluntarily in this experiment/design workshop.

\textsuperscript{40} Cross, N (ed) Development in design methodology John Wiley & Sons, Chichester, UK (1984)
Students were then divided into two equal groups of 15 each, the ‘pilot’ group and the ‘main’ group, based on the last two digits of their matriculation number and whether the number made by the two digits was odd or even. The feedback from the pilot group experiment was helpful in revising some aspects of the ‘main’ group experiment including CAAD’s teaching, length of practice sessions and the lucidity of the questionnaire. The results presented here are those of the ‘main’ group. Student volunteers were aware that this was a short design workshop using 2D and 3D AutoCAD AEC (in the meantime superseded by Architectural Desktop 2)\textsuperscript{41} as the only drawing and modelling tool, that it was not necessary to have any previous CAD experience, that the purpose was to investigate the effectiveness of the computer as the sole development tool in the design process. Students did not expect anything in reward; their motivation for participation was to learn new CAAD skills and use them in future design work.

The design programme was then introduced. This took the form of a general outline of the programme and the description of the requirements of the brief. A precedent, the Studio in Chislehurst, Kent designed by Patel and Taylor, was used to illustrate how a small building had been placed and circulation organised on a site with similar but not identical characteristics and context as their own. By doing this the issues of ‘threshold’ and ‘route’, entry and domain were discussed.

Students were then shown ‘sketch’ and other basic controls of AEC. Once these modes had been demonstrated they were given time (three hours) to practice. After showing students how to generate irregular surfaces and solids from two-dimensional (2D) concentric polylines, later that afternoon everyone was asked to draw the site in three dimensions using AEC. This provided a scaled representation of the site context that could be used to explore, examine and develop design ideas. The outcome of site drawing was a varied success—from abstract representation to detailed 3D drawing.

At the start of the following morning a precedent studios talk was given. The aim was to stimulate thought about alternative organisational strategies that could be used. Three buildings each with different design emphasis were described. They were all examined in relation to Louis Kahn’s ‘served and servant’ concept. Benthem and Crouwel’s ‘relocatable house’ in Almere of 1985 illustrated an ‘inhabited wall’ service zone. Monarch’s Leisure Studio in Finland of 1994 demonstrated the use of a ‘free standing service core’ placed within a simple volume to organise spaces of varying size. Ellen Dunham-Jones and W Jude Le Blanc’s studio in Charlottesville, Virginia of 1992 showed how the served, service and circulation spaces could all be articulated separately. Although none of the examples chosen

\textsuperscript{41} AutoCAD 14 AEC 5.1 user guide Autodesk Ltd, Guilford, UK (1997)
had the same brief and they all had different contexts, we were able to abstract the essential conceptual and organisational ideas and also start to outline some different spatial and aesthetic approaches.

After this the introduction to AEC continued. The students were shown how to establish multiple windows on the screen each with a different viewpoint of the site. This allowed them the opportunity to see the implications of their proposals and any changes made simultaneously in plan, axonometric and perspective. They were taught how to select a viewport and zoom in on any chosen part of the drawing to examine or modify it. During the day they were also shown how to create walls, windows, doors, floors, columns and roofs.

The third day began in the computer room learning how to construct *design compositions* using solids and openings in solids, making an animated walk-through, creating layers, annotating and printing, and plotting copies of drawings.

During the afternoon visits were made to the Architecture Department’s darkroom and the Glasgow School of Art’s Graphics Department to acquire a visual description of ‘real’ spaces/studios in use.

The next three days were set up as tutorial days when both computer and design lecturers were present as students explored initial ideas. The students were developing both their understanding and skill using the computer while at the same time exploring ideas. During this period we had asked them to use the library for further research and study of precedents. We deliberately dissuaded the students from using any means other than the computer to form ideas, so that we would be better able to assess the implications of designing with the computer only. This restricted them to the computer room and its hours of opening. If they were unable to contain themselves we asked them to bring in with them all other development work. Most, however, were able to work within the restriction. All tutorials were also given round the computer screen using either the simple sketch command or asking the student to modify their proposal in a specific way.

For the final three days of the design period the students were primarily working on their own with limited access to lecturers. Towards the end of the session a seminar was held to talk about how they might best describe their proposals. Different methods of using the VDUs effectively were discussed. They then had time to think about their presentation and make the necessary preparations.
Our reviews of the students’ work were held in the computer room around the computer screen. Varied presentation formats were used. Some students conveyed their ideas using a sequence of views on screen including a ‘walk through’ animation, others subdivided the screen into multiple viewports and zoomed in on specific images as necessary or in response to a request for further information. The reviews were more interactive than usual and it was easier to identify the issue being discussed as the relevant image would be the focus on the screen.

3.2 General appraisal of the CAD program used in the research

AEC is an add-on to AutoCAD which, like many other CAD programs on the market, allows the designer to see his or her proposal in multiple views at the same time on the screen. These could quite easily include plan, section, elevation, axonometric and perspective side by side. This allows the designer to see the implications and potential of any design move more fully and in so doing open up options that might otherwise not have been so evident. If a change or modification to a drawing is made it is made to all of the drawings simultaneously, so saving time adjusting each drawing separately. This allows more time to be spent on the refinement and development of the design.

It facilitates the creation of a 3D shaded ‘walk through’, which provides a better understanding of the nature of the building form and spaces being proposed. It also offers other insights into the spatial sequences and the experience they create and becomes much closer to the kinaesthetic experience of walking through a building, and this in turn could better students’ perception of form and improve ‘design cognition’.

The option to create layers gives the designer the opportunity to produce additional degrees of information and detail. This in turn allows the designer to convey an idea fully or abstract specific information for further examination and development. It also reduces the need to duplicate drawings. For example, the essential idea can be conveyed using only linear presentation to assess the quality of the spatial organisation and form, or additional layers could be used to show materiality, mass, transparency, colour, texture, use of natural light, denote size by dimension, and describe activity and use with annotation or habitation with people and furniture and fittings.

If AEC were linked with other programs—i.e., structures, lighting and environmental management—it would undoubtedly offer other design development and appraisal possibilities, many of which are already evident.

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in architectural practice when architects and consultants work together and exchange information by E-mail.

As a linear design tool AEC is excellent. It demands that the designer make decisions to make the next drawn move. Without the decision there is no progress. Once the proposal/modification/change is made it can be recorded and viewed in different ways and drawing systems simultaneously on the screen, which allows a greater understanding of the design implications. These can then be appraised and the next move considered and made. The process forces the pace of decision-making and is ideal in a linear design development situation.

The AEC ‘sketch’ option has limitations as a means of drawing. The use of the mouse to draw free-hand takes more time and demands far more control than pencil and paper. It does not have the range of thickness and intensity and it therefore cannot express the weight and emphasis intended in aspects of a drawn idea. The lack of fluidity hinders the range, speed and flow of drawing as a design tool in the initial stages when designers need the freedom to explore ideas. They need to be able to think laterally and work around an idea and take advantage of chance. With AEC the demand for a command to allow a progression to the next stage requires the designer to be constantly conscious of each decision. This makes it more difficult to key into the subliminal and take advantage of the subconscious and serendipity.

AEC has a range of built-in geometric and type options. If a designer does not wish to work within this framework he forfeits one of its advantages—speed of response. This is in effect a penalty and it may encourage the less ambitious to take the easy route and work within the given program. To overcome this the designer has to have a greater level of skill to generate his own formal language and components, and therefore has to be more determined and work harder. This is not necessarily uncommon in the design field as any designer who is pushing out the frontiers usually has to work harder in order to prove his ideas and achieve. The computer room’s internal environment is not a good conducive design atmosphere compared with the studio.

4 Case study: concept definition and methods of data collection
Fifteen second-year students volunteered to take part in the experiment and use the computer in the design of the studio. Questionnaires were administered to students at two points in time, or under two different conditions: once before using the computer–CAD package to design the graphic
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designer’s studio and once after using the computer. Similarly, the response was collected at two points in time, measured on a five-point scale, and analysed statistically by using SPSS (Statistical Package for the Social Sciences)\textsuperscript{42}. The questionnaire sought information on:

(1) Student views, at two points in time, on the computerised design process in terms of sketching, model-making and time required for decision-making (DM)—before using the computer and after using the computer.

(2) Student attitudes, at two points in time, towards the relationship between the automated design process and design issues such as creativity, intuition, innovative and intelligent design decisions, composition, cognition. Again views on these issues were sought before using the computer and after using the computer.

(3) Areas of the design process where, in student views, the use of the computer can yield maximum impact/benefit. Student views on this issue were collected only once—after using the computer.

In addition, students were made aware of the operational definition of some concepts/issues deemed to be very relevant to design. For instance,

(4) Creativity as a concept was operationalised using Vernon’s definition of it being the capacity to produce original/new insights, or artistic products that are appraised by the experts as being of technical, social and aesthetical value\textsuperscript{43}. Intuition is another concept which is very closely associated with creativity because the process of arriving at creative products involves making intuitive decisions. Intuitive thinking has been defined as the ability to arrive at conclusions from fewer clues than would be required by the average person\textsuperscript{44}. In architectural design a great deal of intuitive thinking occurs at an early stage of the design process—formulation of the design concept. Relevant to creativity are intelligence and complexity, the assumption being that intelligence affects creativity, and creative people prefer complex rather than simple solutions to problems. Empirical findings suggest that creativity/originality correlated with a preference for complex designs; originality did not correlate with intelligence\textsuperscript{45,46}. In this paper students were asked about their views on whether or not the computerised design process can help their design creativity, enhance their ability to make intelligent design decisions, and succeed at reaching complex design solutions. Students’ response was measured on a ranking scale of 1 to 5, with 1 = ‘little help’ and 5 = ‘great help’.

(5) Cognition is the study of mental operations involved in receiving, storing and processing of information. Oxman argues that cognition in the design process is directly affected by mechanisms including vision

\textsuperscript{42} SPSS-PC Statistical Package for Social Sciences base 7.0 Application Guide, Chicago, IL (1996)


\textsuperscript{44} Westcott, M and Ranzoni, J ‘Correlates of intuitive thinking’ Psychological Reports No 12 (1963) pp 595–613

\textsuperscript{45} Barron, F ‘Complexity–simplicity as a personality dimension’ Journal of Abnormal and Social Psychology 48 (1953) pp 163–172

\textsuperscript{46} Welsh, G S Creativity of intelligence: a personality approach University of North Carolina Press (1975)
and perception, thought processes, concept formulation, and analogical thinking and reasoning. Design composition, on the other hand, is the study of the relationship between three-dimensional forms. Design compositions can be produced with forms being either apart—not touching, or in contact—touching which includes overlapping, interlocking or interpenetrating. This research assumes that the use of the computer, with its excellent visualisation tools, will enhance students’ perception of three-dimensional form, and in turn their design cognition, and help them to produce interesting and imaginative composition.

4.1 Hypotheses (H) and H0
Two ‘target’ hypotheses (H)—a statement on the predicted influence of the independent variable (the computer) on the dependent variable (student attitudes)—were put forward for test. Opposite to the target hypothesis is the null hypothesis (H0)—the statistical hypothesis of no difference or no relationship—that can be tested statistically.

(1) H0 ONE: There is no significant difference in student attitudes—before using the computer and after using the computer—towards the automated design process in terms of the variables: sketching, model-making and time required for design decision-making. In other words, does the usage of the computer as a design tool produce a difference in attitudes towards sketching, model-making and time required for design decision-making?

(2) H0 TWO: There is no significant difference in attitudes—before using the computer and after using the computer—towards the automated design process in terms of creativity, intuition, composition-making and design cognition. The question here is whether or not the usage of the computer can help creativity, intuition and design cognition.

To increase the ‘validity’ of this research and move beyond ‘internal’ validity to ‘external’ validity, the experiment has to be repeated for a larger sample.

4.2 Statistical analysis and findings
4.2.1 Hypotheses test using the two-tailed t-test
Student returns were coded and analysed in SPSS using the Paired Sample t-test, recommended by statisticians for measuring attitudes and performance of the same subjects under two different conditions—i.e., student attitudes towards aspects of the design process under two conditions, before using CAD and after using CAD. In addition, the t-test is a powerful statistical test that can produce results even with a small sample size. This
test can be used to test the difference between the means of the two sets of scores for significance. For instance, the difference between the means of student attitudes, in terms of scores, towards the design process variables under two different conditions—before using CAD and after using CAD. As a rule of thumb in statistics, for a difference between two means to be statistically significant, the significance value has to be equal to or smaller than 0.05. In the case of the \( t \)-test, to confirm significance, the \( t \)-value must also be larger than the critical value of \( t \) given in statistical tables\(^{49} \).

For 14 degrees of freedom \((df = 14)\), Table 1, and a significance of 0.05, the tables give a critical \( t \)-value of 2.145\(^{49} \). The italicised values of \( t \) in Table 1 show a significant difference between the two means for all seven pairs of variables except one—pair means the same variable under two conditions. These figures imply that the use of the CAD program has influenced student attitudes towards attributes of the design process such as sketching, model-making and decision-making. V2—CAD is suitable for sketching—was the only variable that did not score a significant means difference—significance = 0.104 > 0.05. The paired difference in the mean between A and B for this variable was very small (0.2667). Before using CAD, students’ response to the question ‘do you think that CAD is suitable for sketching’ was consistent with ‘very unsuitable’ or ‘unsuitable’. After using CAD, students’ response changed slightly but not significantly as they still thought that CAD was not a suitable sketching tool. The computer ‘mouse’ was blamed for being an ‘uninteractive’ sketching device which, unlike the pencil, was difficult to handle and control. V1—sketching is an important aspect of the design process—shows a significant means difference between conditions A and B. The negative value of \( t \) suggests that the mean score of V1 at condition A was lower than that at condition B. V7 registered the highest \( t \)-value (18.065)—the largest mean difference—followed by V4 (14.929). Students intimated that after using the CAD program in the design of the graphic designer’s studio they felt they were making design decisions much quicker than they used to do with conventional media—paper and pencil. They described certain elements in CAD such as space diagrams, layers, dimensioning, area calculations and distance inquiry as ‘very helpful’ and ‘time saving’. During concept formation in the conventional design process, time is divided between sketching and thinking. With the computer very little sketching takes place, and most of the time is spent on thinking and decision-making. V6—CAD can replace physical models—also gave a significant difference of means. Before the experiment students’ response to this issue was different from that after the experiment. Students expressed special interest in Boolean operations which enabled them to create complex objects from primitive solids.
Table 1 The t-test results on Group 1 of the design process variables under conditions A and B, with A = after using CAD and B = before using CAD—H \textsuperscript{0} ONE. Pair = variable (V) under two conditions. df = degree of freedom, the total number of subjects in the group(s) minus the number of groups

<table>
<thead>
<tr>
<th>Pair 1</th>
<th>Pair 2</th>
<th>Pair 3</th>
<th>Pair 4</th>
<th>Pair 5</th>
<th>Pair 6</th>
<th>Pair 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketching is important design process (A)—sketching is important design process (B)</td>
<td>CAD suitable for sketching (A)—CAD suitable for sketching (B)</td>
<td>CAD a useful design tool (A)—CAD a useful design tool (B)</td>
<td>CAD for conceptual design (A)—CAD for conceptual design (B)</td>
<td>Importance of physical models (A)—importance of physical models (B)</td>
<td>CAD replaces model-making (A)—CAD replaces model-making (B)</td>
<td>CAD speeds up DM (A)—CAD speeds up DM (B)</td>
</tr>
<tr>
<td>Paired differencesMean</td>
<td>0.6000</td>
<td>0.2667</td>
<td>2.0000</td>
<td>2.4667</td>
<td>−1.1333</td>
<td>2.2000</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.6325</td>
<td>0.5936</td>
<td>1.0000</td>
<td>0.6339</td>
<td>0.8338</td>
<td>1.4736</td>
</tr>
<tr>
<td>Standard error of the mean</td>
<td>0.1633</td>
<td>0.1533</td>
<td>0.2582</td>
<td>0.1652</td>
<td>0.2153</td>
<td>0.3805</td>
</tr>
<tr>
<td>95% confidence interval of the difference</td>
<td>0.9502 + 6.2067 × 10^-2</td>
<td>1.4462</td>
<td>2.1123</td>
<td>−1.5951</td>
<td>1.3840</td>
<td>3.0551</td>
</tr>
<tr>
<td>Upper</td>
<td>−0.2498</td>
<td>0.5954</td>
<td>2.5538</td>
<td>2.8211</td>
<td>−0.6716</td>
<td>3.0160</td>
</tr>
<tr>
<td>t</td>
<td>−3.674</td>
<td>1.740</td>
<td>7.746</td>
<td>14.929</td>
<td>−5.264</td>
<td>5.782</td>
</tr>
<tr>
<td>df</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Significance (two-tailed)</td>
<td>0.003</td>
<td>0.104</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
and entities—box, cone, line, circle, etc. They described the process as ‘quicker’, ‘easier’ and more intelligent than paper-based models.

The results of the t-test for the second group of design process variables are shown in Table 2. The values of $t$ obtained, which are italicised in Table 2, confirm a significant difference between the two means of the same variable under the two conditions: A—after using CAD, and B—before using CAD. In other words, before using the computer students showed an attitude towards the design process concepts that was different from the one shown after using the computer. This implies that the use of the computer has had an impact on student attitudes toward the design process. It appears that CAD usage has produced different design perception. For instance, on V1—CAD enhances design creativity—where $t = 10.212$, significance $= 0.000 < 0.05$, students intimated that the Boolean operations of union/subtraction of architectural forms in CAD—the AEC program—has helped them to generate new hybrid design forms and configurations very quickly and easily. Some overlapping and intersecting forms would have been difficult to imagine, edit and visualise without the computer. Students saw this creation process as a positive indicator on design creativity. On V2—attitudes toward intuition—the response also registered a statistically significant difference (a $t$-value of 5.77 which was above the critical $t$-value of 2.145, but lower than that for creativity, 10.21). This again suggests that student attitudes towards design intuition were influenced by the use of the computer as some students suggested that it helped their design intuition by enabling them to quickly arrive at design solutions. According to one student, computer visualisation of three-dimensional design helped him to find quick solutions to design problems and design faster than he used to do with paper and pencil. Another student compared design intuition with and without the computer. He argued that with the computer he spent more time on thinking about the design concept and less time on sketching, the opposite of what he used to do with paper and pencil. From personal observations of students while they were engaged with various design tasks on computer, it was obvious that they were apprehending the design problem and arriving at design solutions for the studio quicker that they used to do with conventional media.

V3—CAD helps design cognition—also showed a significant difference in attitudes between the two experimental conditions ($t = 6.5$, significance $= 0.000 < 0.05$). The subjects advised that with the computer they were able to shift from two-dimensional views to three-dimensional views of their design quickly and very frequently. This, coupled with the ability of CAD to quickly generate accurate three-dimensional views of design, were perceived by students as being very helpful for design cognition and design...
Table 2: The t-test results on Group 2 of the design process variables under conditions A and B, with A = after using CAD and B = before using CAD—H 0 TWO. Pair = variable (V) under two conditions

<table>
<thead>
<tr>
<th>Pair</th>
<th>Creativity (A)</th>
<th>Intuition (A)</th>
<th>Design Arch. Voc. (A)</th>
<th>Innovative DM (A)</th>
<th>Complexity (A)</th>
<th>CAD helps enhancing creativity (B)</th>
<th>CAD helps enhancing intuition (B)</th>
<th>CAD helps enhancing design Arch. Voc. (B)</th>
<th>CAD helps enhancing Innovative DM (B)</th>
<th>CAD helps enhancing Complexity (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.4000</td>
<td>2.0667</td>
<td>1.7333</td>
<td>1.2000</td>
<td>2.0667</td>
<td>1.6667</td>
<td>1.6667</td>
<td>1.6667</td>
<td>1.6667</td>
<td>1.6667</td>
</tr>
<tr>
<td>2</td>
<td>0.9103</td>
<td>1.3870</td>
<td>0.8619</td>
<td>0.6109</td>
<td>0.8837</td>
<td>0.5926</td>
<td>0.5926</td>
<td>0.5926</td>
<td>0.5926</td>
<td>0.5926</td>
</tr>
<tr>
<td>3</td>
<td>0.2350</td>
<td>0.3581</td>
<td>0.2667</td>
<td>0.2225</td>
<td>0.2108</td>
<td>0.2108</td>
<td>0.2108</td>
<td>0.2108</td>
<td>0.2108</td>
<td>0.2108</td>
</tr>
<tr>
<td>4</td>
<td>1.8959</td>
<td>1.2986</td>
<td>1.1614</td>
<td>1.4947</td>
<td>1.5773</td>
<td>1.4947</td>
<td>1.5773</td>
<td>1.4947</td>
<td>1.5773</td>
<td>1.5773</td>
</tr>
<tr>
<td>5</td>
<td>2.0904</td>
<td>2.3053</td>
<td>1.6773</td>
<td>2.6386</td>
<td>2.1188</td>
<td>2.6386</td>
<td>2.1188</td>
<td>2.6386</td>
<td>2.1188</td>
<td>2.6386</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
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<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>
conceptualisation. V4—CAD enhances the architectural design vocabulary—yielded a significant difference in attitude \( (t = 5.39, \text{significance} < 0.05) \). The many libraries of building elements (walls, roofs, slabs, stairs, windows, doors, etc.) in AEC were perceived by the students as being a large visual database, useful for improving their construction skills and enhancing architectural knowledge and vocabulary. V5 and V6 yielded significant differences in attitude between conditions A and B \( (t = 7.75, \text{significance} < 0.05; \ t = 7.90, \text{significance} < 0.05) \). Students felt that the use of CAD had made the decision-making process of design both ‘innovative’ and ‘intelligent’. They conceded that with CAD it was easy to create and edit three-dimensional forms very quickly, assign materials, colour and textures to them, then generate a quick walk-through. This made the design process interactive, interesting and realistic. Furthermore, the built-in facility in CAD that simulates both natural and artificial lighting and generates sun studies and shadows, was extremely useful in making well-informed and intelligent design decisions. In V7, students were asked about the influence of using CAD on design thinking in terms of preference for complexity or simplicity of the generated design forms. The results confirm CAD’s impact on attitude toward the creation of complex/simple forms—\( t = 9.05 \). Most students emphasised the fact that the CAD’s Boolean operations have great potential as cognitive tools to produce non-linear, complex, penetrating and organic design forms.

### 4.2.2 Findings on CAD’s impact on the design process: descriptive statistics

Students were asked to identify which stages/areas within the design process the use of CAD had made a big difference and contributed positively towards the design process. The response was measured on a five-point Likert scale—1 = least impact, 5 = maximum impact. The results are shown in Figures 1–3. The response, Figure 1, can be grouped under four categories. Group 1 includes the areas of drafting (mean score of 4.5 out of a possible 5) and lighting (4.5), both produced the highest score followed by architectural presentation (4.2) and sun study (4.1). Group 2 consists of design cognition (3.8) and composition design (3.6), very close to each other. Group 3 is made of two variables: CAD speeds up the design process (3.4) and CAD is useful for visualising construction details (3.0). Group 4 contains only one variable—sketching—which produced the lowest mean score (1.5). It is evident that students perceived CAD as being least beneficial to the ‘sketching’ stage of the design process. This can be attributed to problems with software and hardware. Firstly, most CAD softwares have failed to embrace sketching as an important design activity, and consequently provided very little in terms of computerised menus and commands for unstructured free-hand sketching. Secondly, input devices like the
mouse and the keyboard, unlike the pencil, are awkward to handle and interact with.

Figure 2 shows the cumulative sum—students’ overall score on each design process variable thought to be affected by the use of CAD. The areas of lighting (67 out of a possible 75) and drafting (66) produced the highest cumulative sum. ‘Design cognition’ and ‘composition design’ were very close in terms of their overall sum. This implies that these two areas were seen by students as related or associated with each other. Indication on
An inquiry into computers in design: attitudes before—attitudes after

Figure 3 A box plot depicting the range on a five-point scale of students’ attitudes towards CAD’s impact on the design process.

This plausible relationship has been examined further using correlation tests—Table 3. The same cannot be said about lighting and drafting as the two concepts are not logically related. A link between lighting and sun study seems plausible for further investigation via correlation techniques. Cumulative response on ‘sketching’ was the lowest of all, and is consistent with the mean response (Figure 1).

Table 3 The correlation test identifying relationships between some variables of the design process

<table>
<thead>
<tr>
<th></th>
<th>Composition</th>
<th>Design cognition</th>
<th>Sun study</th>
<th>Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spearman’s rho</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composition</td>
<td>1.000**</td>
<td>0.538*</td>
<td>0.824**</td>
<td>0.561*</td>
</tr>
<tr>
<td>Design cognition</td>
<td>0.538*</td>
<td>1.000</td>
<td>0.762**</td>
<td>0.048</td>
</tr>
<tr>
<td>Sun study</td>
<td>0.824**</td>
<td>0.762**</td>
<td>1.000</td>
<td>0.400</td>
</tr>
<tr>
<td>Lighting</td>
<td>0.561*</td>
<td>0.048</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Significance (two-tailed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composition</td>
<td>0.039</td>
<td>0.039</td>
<td>0.000</td>
<td>0.030</td>
</tr>
<tr>
<td>Design cognition</td>
<td>0.039</td>
<td>0.001</td>
<td>0.001</td>
<td>0.865</td>
</tr>
<tr>
<td>Sun study</td>
<td>0.000</td>
<td>0.001</td>
<td>0.139</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>0.030</td>
<td>0.865</td>
<td>0.139</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (two-tailed).
** Correlation is significant at the 0.01 level (two-tailed).
the design process issues—Figure 1—were clustered around any one category of the five-point scale. Each box shows the median, quartiles and extreme values within a category. For ‘sun study’ the range of response was between 3.5 and 5, although most of the scores revolved around the 5 category (maximum impact/benefit). For ‘architectural presentation’ most votes were within the 4 category of the scale. A bigger range means that the vote was more dispersed (less clustered), giving rise to a slight inconsistency between student responses. The marks in the figure around the variables ‘design cognition’ and ‘design composition’ are called ‘outliers’, which means that some of the response fell outside the range/quartile but was not strong enough to create a distinctive zone and disturb the median.

It is obvious that maximum consistency between students was on the issue of CAD’s impact on ‘design composition’. The response included answers like CAD is good for making ‘design compositions’ based upon penetrating and intersecting forms.

4.2.3 Correlations: inferential statistics

The relationship between variables of the design process was examined using Spearman’s correlation test. Any coefficient equal to or greater than 0.5 was taken as an indicator of a strong positive relationship between the two variables being investigated. In other words, a correlation coefficient larger than 0.5 implies some ‘cause’ and ‘effect’ relationship between the two variables. The results from the test are presented in Table 3.

It is obvious that a significant relationship existed between ‘design cognition’ and ‘design composition’—a coefficient of 0.538. A possible explanation could be that design cognition was very much improved by CAD’s powerful ability to generate three-dimensional forms and contribute to design visualisation. This newly acquired state of improved cognition must have helped students imagine, create and explore a variety of intersecting and overlapping design compositions. One could argue that computer visualisation has influenced cognition which in turn has positively affected the process of creating design compositions. Design composition was found to correlate very strongly with sun study (coefficient = 0.824) and strongly with lighting (coefficient = 0.561). A simple interpretation for the two associations could be that any change in the organisational relationship between design forms—i.e., composition—will affect shade and shadow patterns on horizontal and vertical surfaces, and also levels of daylight inside.

The relationship between ‘design cognition’ and ‘composition design’ was examined further by using a scatter-plot. This is more visual than the correlation test and also gives an indication of how much a change in one
variable will affect the other. The inclined line in Figure 4 indicates that the relationship between cognition and composition is ‘linear’ one, with a degree of ‘variance’ of 0.4064. This figure implies that around 40% of change in ‘composition design’ was caused by a change in ‘design cognition’.

The remaining 60% change in composition should be attributed to other variables which are beyond the scope of this investigation. The horizontal line in Figure 4 represents students’ mean response on CAD’s impact on design cognition, which was found to be 3.8 out of a maximum of 5.

Finally, it is important to mention that literature on research design of ‘classical experiments’ advocates the use of a ‘control’ group to overcome the problem of internal ‘invalidity’ of research. However, for a control group to have any value, the experimental and control subjects have to be kept separate to ‘reduce the possibility of diffusion or imitation of treatments’\(^5\). The condition of ‘separation’ between groups could not be met by the research experiment due to the context within which it took place. In a design studio setting it was difficult, if not impossible, to separate a group of students from their colleagues for the duration of the experiment.

5 Conclusions
There are two well-established methods of knowledge acquisition. The ‘romantic’ view, advocated by Plato, maintains that knowledge can be acquired through intuition and experience. Some would argue that design
is an intuitive process and models of design should embrace this view. On the other hand, Aristotle’s ‘classic’ view calls for knowledge to be obtained by the study of underlying form and structure using reason and laws. With this in mind, this research set out with the intention of applying ‘classical’ research methods and statistical techniques to analyse a ‘design experiment’, which is highly intuitive.

The main conclusions that can be drawn from this study are summarised below.

(1) The findings from this study have confirmed the importance of sketching as an act of designing. However, when students were asked to use CAD tools only, they modified their design approach. Instead of using the conventional approach of sketching⇒concept formulation, students shifted to a new approach—a CAD approach—of thinking⇒concept formulation. Further empirical research is needed to assess the impact of this shift on the quality of design solutions.

(2) Both null hypotheses (H₀ ONE and H₀ TWO)—of no significant difference in attitudes towards the design process before using CAD and after using CAD—should be rejected. Students’ response to several aspects (variables) of the design process changed after using CAD for designing the studio. CAD was found to help design cognition, creativity and intuition. CAD as a tool was found to have a profound impact on many areas of the design process through its various advantages in lighting simulation, sun study analysis, presentation, and in making design compositions at the early design stage.

Finally, it is hoped that this research has to some extent established a ‘framework’ within which the problems of using CAD as the only design tool can be addressed. However, there is a need for further ‘applied research’ into this area where proper research methods and techniques should be employed on a bigger sample using a different CAAD program. Also, experimental research is needed in architectural offices, where the context is different and the subjects are experienced architects whose design knowledge/experience is greater than that of our ‘novice’ students.

**APPENDIX**

Two of the images (image 1 and 2) in Figure 5 are an attempt by the student to use CAD as a tool to enhance the creation process of design composition. The student has created a ‘penetrating’ design composition by breaking the rigidity of the linear grid with a diagonal, non-orthogonal mass. The four remaining images (3–6) belong to two projects. In the first three images (3, 4 and 5) the student has explored the relationship between function and form in a progressive manner with some emphasis on details.
An inquiry into computers in design: attitudes before–attitudes after
Image 3

Image 4

Image 5
and site layout. In the fourth image (image 6) the student’s emphasis was more on using CAD to produce Platonic forms, explore material transpar-ancy and simulate light and shadows.