

THE CHANGING ROLE OF CAAD AT THE ARCHITECTURAL DESIGN STUDIO

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ABSTRACT: This study is concerned with exploring students' use of CAAD software programmes, which are already available in studios and schools of architecture - to better reflect the status of CAAD in the educational context at the studio, while CAAD is not an integral part of the studio teaching. This study also anticipated providing a "real-context" appraisal for CAAD related issues and to know what is behind the tendency to use CAAD early in the conceptual phases of the design process. At the general level of inquiry a questionnaire survey was designed and circulated. Thus, by directly observing studio activities, the study can develop an understanding of the modern context within which the study operates. This included interviewing students through part of their design reflection at the studio and acting on those observations from a process methodological point of view. This study was able to clarify the effects of computers on the traditional context of the architectural studio and how to reflect that on the teaching method, taking in consideration the primacy of drawings as a medium for design.

Keywords – Architectural Design, CAAD, Design Process, Drawing, Education.

1. INTRODUCTION

At the present time, it is apparent that architectural students finalize their conceptual design propositions using one or more CAAD software programmes as a representational mode of thinking (i.e. Ataman, 2000; Al-Qawasmi, 2004, 2005). By creating these drawings, a student's main endeavour is to convey design ideas as well as to attract the reviewers' attention and their positive appraisal. On the other hand, this representational mode has a hidden side to the same process, being the rationale behind the creation process of these drawings.

It is of interest to know how these drawings were created at the early phases of their development and what the conceptual process was behind them. Does CAAD help in creating these innovative designs? Is there any impact on the student's performance in conceptual design? Or, was a design created via a different visual thinking method and presented by CAAD programmes? This study is interested in the situation in which a designer would choose to use CAAD media as a conceptual tool in the conceptual design phases.

2. AIM AND OBJECTIVES

This paper is part of an on-going doctoral research. The main objectives of this study are first, to explore CAAD software programmes, which are already available in studios and schools of architecture and to know how to define the status of CAAD programmes in the educational context at the studio, while CAAD is not an integral part of the studio teaching.

The second objective is to provide a "real-context" appraisal. By directly observing studio activities, the authors can develop an understanding of the modern context within which the study operates. Observing students through part of their design reflection at the studio and acting on those observations from a process methodological point of view.

The third objective is to know what is behind students' tendency to use CAAD software programmes in the conceptual design process and what would motivate the student to use CAAD software programmes early in the conceptual design process? How can CAAD facilitate the exploration of designs early ideas? What are the means of CAAD medium which allow this to be possible? Does this promote their design problem solving or the design talk back?

Earlier study (Salman et al, 2006) for the same authors looked at the conceptual design iteration process, by observing the subjects' behaviour in solving the design task. It showed that the use of conventional techniques and methods, in solving a design task, is the basis for the occurrence of design conversation through an interactive conceptual process. Please refer to section 5.3.

3. COMPUTER'S EFFECT ON THE ARCHITECTURAL STUDIO

3.1 The Educational Setting

While students are becoming more computer skilled and digitally literate, they are imparting knowledge and skill (Bermudez and King, 2000) to the traditional context of architectural learning. Arguably, the studio tradition of architectural design learning is consistent with centuries of architectural teaching methods. What might impact the studio culture is the changing design media and the visual impact that each can bring. Currently, describing a contemporary design studio would make it seem rather classic, but describing the engagement with various media would open up new perspectives for design thinking. This view was confirmed by Breen (2004), Schenk (2005) and Salman et al (2006) studies.

In recent study (Achten, 2003; Al-Qawasmi, 2004, 2005), the challenges have been extended to include the need to develop new skills, rethink architectural design education in the light of the new developments in CAAD software programmes, and reflect how this might bring the change to the traditional cultured setting.

In terms of design computerization, Andia (2002) study identified that professional practice and architectural education are developing different arguments about computerization. Architectural practice is effectively improving the architects traditional ways of design by digital technology integration. Whereas in academia computers have been used in architectural schools to challenge the view of architectural practice; the architectural studio becomes the setting to examine the computers tributary role in architectural design. In academia, many support this "modernizing" view (i.e. Schenk, 2005). Therefore, an increasing number of architectural schools are becoming an exploration setting for various design media interactions and integration (Ataman and Lonman, 1996; Bermudez and King, 2000; Ataman, 2000; Al-Qawasmi, 2004, 2005; Knight et al, 2005). As we shall see, CAAD software programmes continue to affect architectural thinking in a number of ways.

3.2 CAAD Impact On The Studio

Literature review suggests hand sketching and CAAD visual techniques can be used in conjunction, rather than being treated as separate medium. Breen et al (2003) also indicated a similar thought on the transition between the physical models in computer aided modelling methods. All of these techniques can contribute to a better evaluation of the envisioned design product. Different media 'talk back' in different ways (Schön, 1989; Breen et al, 2003; Lawson, 2004). The combination of techniques can make things particularly interesting,

giving the designer added insights and more means to (re) consider and (re) fine a design. This possibility opens new horizons in architectural education as well as in architectural medium research (Bermudez and King, 2000).

Design media variation is housed in the introduction of CAAD software programmes (i.e. SketchUp, Photoshop, and AutoCAD); Breen (2004) observed that this introduction has led to develop more personal and varied working methods on both sides of the media; digital and physical. The increasing tendency to mix physical and digital media is making design media interactive (Breen, 2004). Therefore, the change includes various shifts in design media, visual thinking and design teaching theory.

These media shifts go beyond the type of CAAD programme to include personal methods of integration and association between digital and physical mediums, 2D and 3D formats, and any other media that assists the designer in concept (re) structuring (such as photography) and (re) interpretation.

3.3 The Studio Curriculum

At the beginning, adding CAAD to the architectural studio curriculum faced a strong rejection by the studio's professors, thinking that CAAD skills would affect the students' willingness to acquire traditional drafting and design skills (Bille, 2002). With time, professors and students developed an attitude of practical realism as they drew from the developments in practice. Until the early 1990s, CAAD literary courses were accepted and introduced into the curriculum of architectural education (Andia, 2002) and developed through many years of research. Moreover, as CAAD became more powerful and widespread, CAAD proficiency has become pre-requisite to employment after graduation.

More often, the proposed curriculum was never successful in integrating computer literacy with design inquiry. This fragmentation was realized and brought together by the students. Bille (2002) explains that using the computer for communication, writing and other purposes already familiar to the student has facilitated integration of computers in architectural projects. This could reflect the students' motivation to use computers in everyday life as a social phenomena rather than a learning tool. This effect was brought indirectly to impart new skills and tradition on the studio context.

On the other hand, Schenk's (2005) study looked at the teaching of drawing in the digital age by collecting attitudes from senior academics in the United Kingdom on the place of drawing in higher education curriculum. This study claimed that most of the sample believes that students still have to be able to envisage ideas and communicate them through traditional means of drawing. Also, students have to be able to imagine and conceptualize clearly before moving into the digital media and that gaining experience of traditional drawing methods was the best way to achieve this. In respect to this suggestion, this would benefit students to develop their own personal approaches, and then learn how to use drawing appropriately for professional practice (Schenk 2005). Design curriculum should apply more attention to the classic forms of drawing. In that respect (Madrado, 2000) study, digital visual representation can be used for an enhanced visual thinking medium and this might justify why digital media should be seen as an integral part of the drawing curriculum not the opposite (Schenk, 2005).

4. DRAWING AS A MEDIUM FOR DESIGN LEARNING AND CAAD

In general, drawings are the main visual language that architects use as a design medium to conduct their design process dialogues. Architects are trained to combine different sources of

information visually. When applying graphic thinking; different graphical tools help architects through designing but the real test of its convenience has to be made within the context of the individual design process that each designer will develop through many years of practical experience and observation. That is, the development and support of individual design thinking is best promoted by the individual designer (Lawson, 2004; Schenk, 2005). To be an effective process, architects have to be comfortable with their own methods of thinking and recognize the importance of selecting the best tool, environment and method to suit their thinking style. Sketching is a form of visual expression for generating ideas and communicating ideas. According to Lught (2000), visual expression is an inherent part of the creative design process. Architects have a creative perspective in solving design problems and they are open to new ways of seeing the environment. One can assume that designers are able to see all the significant aspects of their emerging designs in their own drawings. In McKim's (1980) words "...abstract and concrete imagery are complementary. The flexible visual thinker moves readily back and forth between the two". One important sense of sketching is that of exploration, the purpose of exploration being to alter graphic images to obtain a new understanding of them. McKim (1980) mentioned that it is important to let the mind wander and be open to unexpected results not tightly focused. Suwa et al (1998) went through sketches to find out how they could be a good medium for effective dialogue. Many studies (Verstijnen et al, 1998; Elsas; Vergeest 1998) considered hand sketching and physical model making are the most important mediums of idea generating process, as digital sketches are argued to not support creativity in the conceptual design phase (Verstijnen et al, 1998; Elsas and Vergeest, 1998; Do et al, 2000).

Other studies like Breen (2004) and Al-Qawasmi (2004, 2005) have also recognized drawing, within digital or physical platform, as the most elementary medium for design thinking. Also, photographic images are used extensively by the students either as a record, precedent or inspiration, this makes photography another medium for alteration (Wilcox, 2004). This also includes the manipulation of available images, acquiring images from physical models and other opportunities like collage. According to Wilcox (2004) the analogical aspects of imaginary pushes the boundary of visual familiarity and references.

Schenk (2005) acknowledges introducing the traditional context to new computerized based drawings, since it can bring new beneficial effects on students, designers and researchers and enable them to have new insights and opportunities to visualize their ideas and to explore new forms of drawing. This integration might have the potential to change the culture of such traditionally protected academic environments. However, a decreasing engagement in traditional paper-based drawing could effect the development of visual literacy and creativity in design students, and the predominance of particular software (Schenk, 2005).

5. EXPERIMENTAL DESIGN

5.1 Design Research Methodology

Cross (1999) gave an extensive summary of the kinds of methods that design research might involve. These include interviews with designers (Cross, 1999; Lawson, 1994), observations and case studies (Achten, 2003; Cross, 1999) and *Reflection and theorizing* (Schön, 1987; Simon, 1981). *Most of these methods are used* for researching the design ability and to obtain designers reflections on the processes and procedures they are using (Cross, 1999).

Schön (1987) looked at the studio context as patterns of 'doing and coaching' and a model for artistry teaching. In terms of the architectural design learning and teaching context,

contemporary studio still embraces its traditional ways of learning by doing. Where students are spontaneously experimenting with conceptual issues as well as making new (unexpected) discoveries (Tversky, 2001; Do and Gross, 1999). It is called 'knowing in action', and it is concerned not only with knowing but also with learning; thinking back and knowing what the student has done since the start of the studio project to the point where to present the design option(s). Recalling this sequenced process of continuous reflection on a design situation at a later stage is described as the '*reflection on actions*', which has no relation with the present actions (decisions) of the student. This might indicate that the process of reflection on action takes a longer time to be explicit. This sequenced process also includes sub reflection processes, where the student knowing and learning would contribute to the design situation in hand at the present time while doing it. That is exactly what has been achieved, from the previous study, through protocol studies (Salman et al, 2006). Schön (1991) termed this process as '*reflection-in-action*' where studio reflection is an approach to decision-making and problem solving.

5.2 The Study Sample

For the purpose of this study, to increase the 'validity' of this study and move beyond students' cognitive differences (i.e. sketching, computer literacy, CAAD skills), the sample chosen was to be an advanced class (5th year architectural students) as they have finished at least four years of studies at the school. It is appreciated that this sample may not be truly representative of all final year students nationally but, as semi-expert designers, they have been designing architectural designs for at least four years and would have acquired and developed various design skills and practices. Furthermore, their studio nature incorporates old and new systems of architectural making and doing. In respect to architectural making, students are free to choose their design representational-media, which they do believe, would make them able to envisage their concepts, whereas they are not encouraged directly to use computer programmes early as part of the studio teaching curriculum. The studio is equipped with several computers, but mostly consisting of drawing tables to enable students to work on projects conventionally. Therefore, the students' choice of media is elective and spontaneous.

This advanced studio encourages various modes of inquiry aiming '*to systematically evolve a compelling architectural proposition coming to an understanding of its significance within contemporary architecture*' by: (a) *setting up the theme or themes of study*, (b) *setting up the techniques for forming and presenting the study*, (c) *documenting the process of this*' (Wolf, 2006).

5.3 The design

At an earlier stage of this on-going research, the research questions were tested by conducting a series of protocol studies, where retrospective think-aloud methods were used as a reflection in action model but were carried out under laboratorial conditions (Salman et al, 2006) not within a "real-context". Although, this methodology was useful to explicate the content of designers' drawing actions and design intentions, it has disadvantages in splitting up the design process from its evolving educational context.

Therefore, a new study was designed to observe and address the visual thinking methods of the spontaneous media engagement within that educational context. Absconding any laboratorial conditions has allowed in order for this study to have various conceptual design

engagements at the early phases, as well as the later phases of design conception, for an extended period of time.

5.4 Procedures

This study was designed to focus on the collection of empirical evidence in assessing the impact of CAAD software programmes on the conceptual phases of the architectural design studio. Data collection methods used in the study included: paper based questionnaire survey, observation (studio's pinups review), and interviews.

The study was completed in two distinct stages. The first stage was completed using a paper based survey to ask the students about their CAAD use tendency at the studio, in relation to other types of media, i.e. sketching and physical modelling. Furthermore, this survey reflects how the respondent group had been taught to think of CAAD programmes in the studio setting. Whereas, the second stage was conducted using an observational methods and followed by conducting interviews at three different intervals during the first semester project duration (11 weeks), involving samples of their visual work.

The observational study involved attending studio pinups and observing student's work through part of their design reflection at the studio and acting on those observations in relation to the conceptual design progress, to identify where the contemporary studio is at the moment and to provide a "real-context" appraisal. The studio observations identified three distinct phases of design development that split data collection into: first phase data (at the start of the project), second phase data (after the second pinup's review) and third phase review (at the third pinup's review - final).

The interviews aimed to identify any association between the rationale behind design concepts and CAAD methods (reflection on action) which students were using. Conducting interviews allows the researcher to collect qualitative data from the students and explore the research questions on a different level of inquiry. Therefore, structured interviews were planned and new questions were formulated. The structured interviews were designed to be performed at the end of each design phase of the process, when students have to pin up their work and be reviewed by their tutors and guest reviewers. The average duration of an interview was approximately 20 minutes. Interviews were recorded on audio tape and were transcribed at the end of the study. After each review, the structured questions were revised and altered in respect to the student's progress. There was also a feedback process that fed into the questions by the researcher. Studio qualitative enquiry is based on the researcher entering the studio; therefore, some initial questions were refined or rejected as a result of the observational data. The revision of the questions was very important to reflect on the progress of the design process. The questions were presented in the same order and wording (Naoum, 2003) to all interviewees.

Secondary data includes the visual representations of the student's design work. This data was important in providing hard evidence of the benefits that students had mentioned in the questionnaire survey. Furthermore, this data was useful to form part of the interview's inquiry at the end of each review, throughout the 1st semester.

6. RESULTS

6.1 Stage 1: Sample Evaluation Survey

Using SPSS package with 50 students (46% females and 54% males), representing a (100%) sample of the year. A descriptive analysis was carried out to provide a general overview of the results to be analyzed and presented in percentages. The average age of the sample is 23 years old. The sample had access to the following computation tools outside the school; half of the students have personal computers, most of the students (82%) have personal laptops, (74%) have internet and 84% have installed one or more CAAD software programmes. Student skill's "self-assessment" questions varied from poor (1) to excellent (5). Preliminary results from the survey data showed that, in general, students ranked their design skills as follows: sketching skill mean score is fair to good (2.82), architectural design skill mean score is good (2.98) and CAAD skill mean score is good to very good (3.68) and this is the highest mean compared to architectural to the other two variables. As shown in table1, in general the sample felt their design skills were good.

Table 1. Statistical table and data box plot: skills - self assessment

	Architectural Design Skill	Sketching Skill	CAAD Skill
N Valid	50	50	50
Missing	0	0	0
Mean	2.9800	2.8200	3.6800
Std. Error of Mean	.08325	.09769	.12917
Median	3.0000	3.0000	4.0000
Mode	3.00	3.00	4.00
Range	2.00	3.00	4.00
Minimum	2.00	2.00	1.00
Maximum	4.00	5.00	5.00

The majority of the sample (84%) uses CAAD regularly in the design process and 64% uses CAAD in both phases (early phases and final phases) of the design process, whilst 32% used it during the final phase only.

Whilst 55% tend to use CAAD as a designing and drafting tool, 45% tend to use it as a drafting tool only. Although CAAD has proved to be useful in presenting architectural designs, 54% of the sample also felt that CAAD affects their work positively in terms of straightening up their pre-conceptual ideas, identifying design problems successfully; communicating and gaining a better understanding of their ideas. They felt that it only had a minor impact on things like, understanding the design brief and expressing the design ideas. However, 67% of the sample reported sketching to be a very important activity to start the design process before moving on to CAAD. Exploring their design early in CAAD has changed their sketching tendency, with 64% stating they tended to sketch less. At the same time, 66% of the respondent group, consider learning CAAD within an architectural practice is the most useful way to learn CAAD as a designing tool. This could be because the integration is well established within architectural practice and the student felt the rational-practical association between CAAD and design.

6.2 Stage 2: Interviewing the Student

6.2.1 Interview: (S-D: P5) Case Study

The study case under review is one of 12 interviews that were collected along the project design lifecycle (11 weeks). This subject has been chosen for the reason that the content of the conceptual design cycle is the most relevant to this paper's hypothesis.

The case study (S-D: P5): [(S refers to subject, D refers to the subject's first name: P refers to Project and 5 refer to the project]. Project no. 5 involves working on *Gray's* school of art extension, and forms part of the university campus development to include an architectural school to the existing building.

Observations: It is a common practice to draw two dimensional diagrams in the form of x and y axis. This is normally to show a 2D view of an abstract drawing: plan, section and elevation. However, in this case study the subject (S-D: P5) showed tendency to use CAAD as a 'drawing board' to carry out form analysis. In order to set his conceptual outline design strategy for the project the subject looked at form generation concepts in architecture and studied similar precedents. This led to thinking about deforming the existing building and proposed a re-union form between the existing building and the new building. To systematically examine the existing building on site the student subtracted the existing buildings (form) into units.

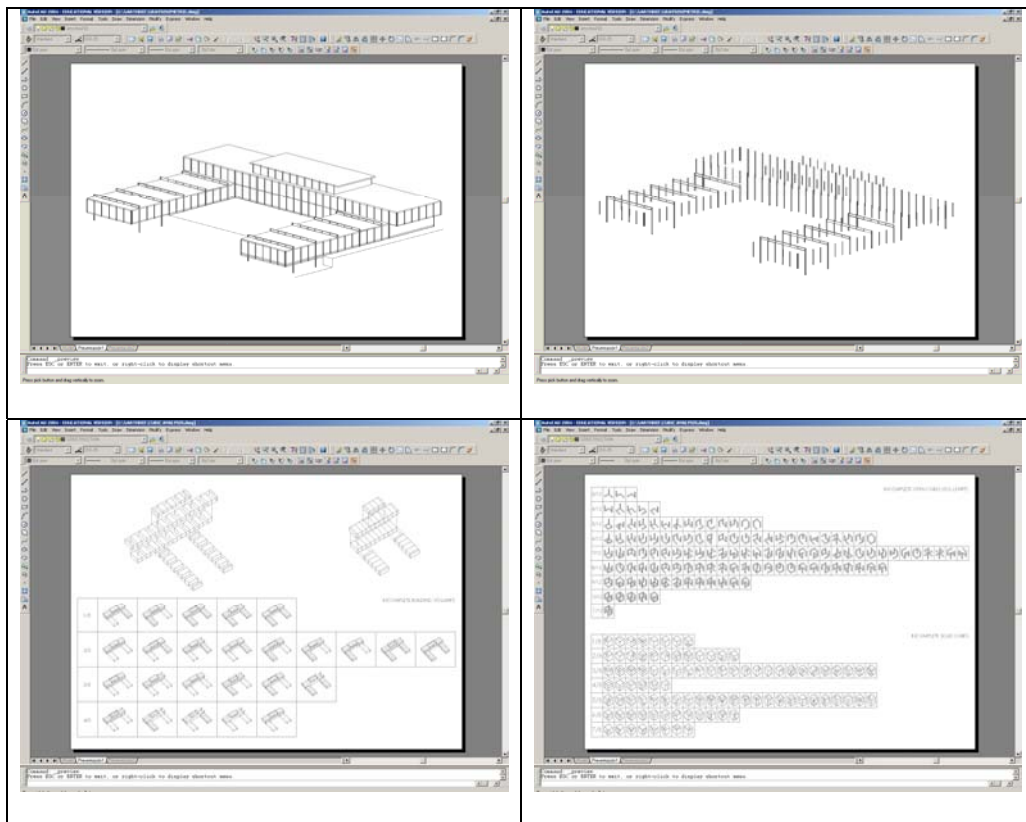


Fig.1. Continual analysis of the existing building

The conceptual design cycle(s): the conceptual design cycle began by looking at various architects, their design methods and architecture. From these precedents studies, it was possible to identify an interesting aspect of what to investigate further: a conceptual

reforming of the existing building. The subject started to draw the existing building in CAAD and look at the structural aspects and relate this with other analysis methods. Through drawing, the subject was able to tackle other aspects of the existing building never understood before. From the subject's perspective these drawings are a continual analysis of the existing building. As these drawings include simple isometric drawing of the building (Fig 1), in fact these are 2D drawings but the subject drew them in an isometric manner to sense the third dimension so one can understand more clearly how the structure works and how the corner junctions are constructed. The second drawing shows only the expressed structure on the exterior of the building and helps to understand the rhythm of the building and the modular nature of the structure as well. These drawings form part of an ongoing analysis of the existing building. As a result of these drawings (form analysis), the subject proposed a new conceptual strategy to apply these reformations to the existing building in respect to the new extension.

7. DISCUSSION AND CONCLUSIONS

Although, the subject(s) considers and perceives CAAD software programmes as a drafting tool, it has affected his conceptual cycle sequences and consequences. As a result of this analogical study, the subject was able to propose an actual building proposal, based on the findings of the systematic investigation of the existing building form. These studies also enabled him to move and make further decisions, as these CAAD drawings assisted his understanding of what the concepts of the work were and the significance of it. Moving to CAAD was came about because, the drawings of the existing building were provided to students previously by the studio tutors which enabled them to explore and see the building's different elements (structure, surface and joints) schematically. Other aspects also mentioned, included: trying different scenarios by repeating the analysis accurately and quickly, changing the drawing appearance easily (line weight) and doing the same task but in a different variation.

Through the interview, the subject showed a tendency toward using CAAD as a tool to investigate a specific conceptual theme (formalism). The CAAD medium is able to relate the subject's design interest in architectural geometrical formation and the conceptual process. The change in the study context includes various shifts in design media, visual thinking and design teaching theory. The relationship between architectural design thinking, representation and media is continual. Media provides the means for engaging in design thinking and progressing via various representational media (Breen, 2004). Although digital media has become an option, this does not mean that digital design should develop into a process, which excludes all other media. Other media, scale-models and sketches, address different sensibilities that better capture other aspects of design.

Moreover, the observational data showed that, students are willing to use CAAD at any point of the project where there is a need for accuracy, neatness and speed. This could be related to design 'talk back' reflection. Although, the subject does not have efficient 3D skills to practice 3D CAAD modelling, by using conventional ways of isometric drawing he was able to achieve a 3D view of his form analysis. This case study confirms Schenk (2005) findings in terms of how to integrate CAAD into the drawing curriculum not the opposite. This gives another example of how students have a tendency to apply conventional design skills to any other visual media; and refers to the potential adaptation (Salman et al, 2006; Breen, 2004; Schenk, 2005).

The combination of physical and digital media and design methods added insights and better means to (re) consider and (re) fine a design. This possibility opens up new

opportunities in architectural education as well as in architectural media research (Bermudez and King, 2000; Breen, 2004). This integration might increase the student's experience of inquiry, discovery and representation (Achten, 2003) and this leads to creativity.

At the present time, the personal laptop has become commonplace at the studio, so instead of carrying a sketchbook, students are carrying and working on their laptop. It acts as an e-sketchbook that includes various aspects of their conceptual ideas and could include: CAAD drawings, scanned-sketches and digital photographs. It houses all types of media that saved digitally to form a reflective journal of their design projects and precedents. Although, they might use various CAAD software programmes to reach the result of this imagery process, it is still housed in one e-book. This is similar to what students had practiced for many years, but to record their ideas by sketching.

This study was able to clarify the effects of computer on the traditional context of the architectural studio and how to reflect that on the teaching method taking in consideration the primacy of drawings as a medium for design.

8. REFERENCES

- Achten, H. (2003) *New Design Methods for Computer Aided Architectural Design Methodology Teaching*, International Journal of Architectural Computing vol. 1 - no. 1
- Achten H.,Reymen I. ,2005, *Structured Reflection as a Means to Deepen Understanding of CAAD*, Digital Design: The Quest for New Paradigms [23nd eCAADe Conference Proceedings / ISBN 0-9541183-2-4] Lisbon (Portugal) 21-24 September 2005, pp. 287-294.
- Ataman, Osman (2000) *Media effect on architectural design*, College of Architecture, Georgia Institute of Technology <http://cumincad.scix.net/cgi-bin/works/Show?83c4>
- Ataman, Osman and Lonnman, Bruce (1996) *Introduction to Concept and Form in Architecture: An Experimental Design Studio Using the Digital Media*, Design Computation: Collaboration, Reasoning, Pedagogy [ACADIA Conference Proceedings / ISBN 1-880250-05-5] Tucson (Arizona / USA) October 31 - November 2, 1996, pp. 3-9.
- Al-Qawasmi, J. (2004). *Reflections on e-design: the e- studio experience*. 1st ASCAAD International Conference, e-Design in Architecture, KFUPM, Dhahran, Saudi Arabia, pp.177-193.
- Al-Qawasmi, J. (2005), *Digital media in architectural design education: reflections on the e-studio pedagog'*, Art, Design & Communication in Higher Education 4(3), pp.205–222.
- Bermudez, J. and King, K. (2000) *Media interaction and design process: establishing a knowledge base*, Automation in Construction, 9, pp. 37-56.
- Breen J., Nottrot R., Stellingwerff M. (2003) *Tangible virtuality—perceptions of computer aided and physical modelling*, Automation in Construction (12), pp. 649– 653.
- Breen J., 2004, *Changing Roles for (Multi) Media Tools in Design: Assessing Developments and Applications of (Multi) Media Techniques in Design Education*, Practice and Research in Digital Design Education(s) [22nd eCAADe Conference Proceedings / ISBN] Volos (Greece) September 2004, pp. 530-539.
- Bilda, Z and Demirkan, H: 2003, *An insight on designers' sketching activities in traditional versus digital media*, Design Studies Vol 24 No 1, pp. 27-49.

- Bille, P. (2002) *From CAD to Communication*, Connecting the Real and the Virtual - design e-ducation [20th eCAADe Conference Proceedings / ISBN 0-9541183-0-8] Warsaw (Poland) September 2002, pp. 156-159.
- Coyne R, Park H. and Wiszniewski D., 2002, *Design devices: digital drawing and the pursuit of difference*, Design Studies, 23(3).
- Cross N., 1999, *Natural intelligence in design*, Design Studies, 20 (1), 25-39.
- Do, E. Y.-L. , 1998, *The Right Tool at the Right Time -Investigation of Freehand Drawing as an Interface to Knowledge Based Design Tools*. College of Architecture. Atlanta, Georgia Institute of Technology: 370.
- Do E., Gross M., Neiman B. Zimring C.: 2000.*Intentions in and relations among design drawings*, Design Studies, 21(5), pp.483-503.
- Do E. and Gross M.: 2001. *Thinking with Diagrams in Architectural Design*, published in 2001 in Artificial Intelligence Review, 15, (1) March 2001 Kluwer, pp. 135-149.
- Dokonal W.; Knight M.; Brown A., 2004, *To CAAD or not to CAAD?* SIGraDi 2004 - [Proceedings of the 8th Iberoamerican Congress of Digital Graphics] Porte Alegre, Brasil 10-12 November 2004.
- Jonson B.:2005.*Design ideation: the conceptual sketch in the digital age*, Design Studies, 26 (6), pp. pp. 613-624.
- Lawson, B 2004, *What Designers Know*, Architectural Press, Oxford, UK.
- Madrazo, Leandro (2000) *Computers and architectural design: going beyond the tool*, Automation in Construction 9 (1) pp. 5-17.
- Mckim, R: 1980, *Experiences in Visual Reasoning*, Brooks/Cole Publishing Company, Monterey, CA.
- McKim, R. (1980). *Thinking Visually: A Strategy Manual For Problem Solving*. Belmont, CA: Lifetime Learning.
- Naoum S. G., 2003, *Dissertation Research and Writing for Construction Students*, Butterworth-Heinemann, Oxford.
- Salman, H., Laing R. and Conniff A. ,2006, *CAAD Visualization Techniques Mediate the Conceptual Design Process as a Thinking Tool: Reflection on action study*, in Communicating Space(s) [24th eCAADe Conference Proceedings / ISBN 0-9541183-5-9] Volos (Greece) 6-9 September 2006, pp. 700-708.
- Schenk, P. (2005), *Reflections on the teaching of drawing in the digital age: attitudes of senior academics in the United Kingdom to the place of drawing tuition on the design curriculum in higher education*, Art, Design & Communication in Higher Education 4(3), pp. 189–203.
- Schön, D: 1987: *Educating the Reflective Practitioner*, Jossey-Bass, San Francisco, USA.
- Schön, D., 1991, *The Reflective Practitioner: how professionals think in action*, Harper Collins, New York, NY.
- Simon, H. (1981) *The Sciences of the Artificial* , MIT Press, Cambridge.
- Tversky, B., 2001, *Spatial Schemas In Depictions*, In M. Gattis, Ed. Spatial Schemas and Abstract Thought, MIT Press: Cambridge, pp. 79-111.
- Oxman R., 2006, *Theory and design in the first digital age*, Design Studies, 27 (3), pp. 229-265.
- Verstijnen, I M, Hennessey, J M, van Leeuwen, C , Hamel, R and Goldschmidt, G :1998, *Sketching and creative discovery*, Design Studies, 1 (19) pp 519-546.
- Wilcox G., 2004, *The Medium and the Thing Itself*, Journal of Architectural Education, 58 (2), pp. 25-27.
- Woolf J., 2006, *March course documentation: An Overview*, Scott Sutherland School: RGU, Aberdeen, November 2006.