CAAD Visualization Techniques Mediate the Conceptual Design Process as a Thinking Tool

Reflection on action study

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This research explores the practical findings of CAAD visualization techniques for the analysis and understanding of early phases of the conceptual design. Our aim is to allow subjects to focus on their design tasks rather than worry about the creation of effective concept presentation. The possibility of a complete computer mediated conceptualization process should be acknowledged as a visual thinking tool. This research will have implications for both how the designer's visual thinking process can be interfaced with CAAD and, perhaps more importantly, may provide new assumptions for the designer's visual cognitive research to explore in order to provide the foundation for more useful tools for designers .

Keywords: *CAAD; architectural design; conceptual iteration; visual thinking.*

Introduction

In many displays of architectural designs, one notices that Computer Aided Architectural Design (CAAD) visual representation is the main final presentation method. It is of interest to know how these representations were created and what was the conceptual process behind them. Does CAAD help in creating these innovative designs? Is there any impact on the designer's performance in conceptual design? Or was a design created via a different visual thinking method and represented by CAAD programs?

Many design studies have focused on sketching and its relationship with creative thinking. However, the potential complementarity between freehand sketching and the use of CAAD as a means of conceptualisation may not have been examined sufficiently.

A great majority of views expressed in the design literature are based on the validation of CAAD programs on the basis of them replacing traditional tools. In contrast, this research examines design issues of visual thinking, conception and drawing, by conducting protocol study experiments exploring visual thinking in the digital design process, and by exploring CAAD programs as new tools for conceptual design and creativity.

Visual thinking and architectural design

Through humanity's evolution, humans' way of thinking has been influenced by two major developments, these being: Language (verbal) and writing or drawing (visual) in its simplest meaning of communicating our ideas, needs and decisions. With those two

modes of thinking we are able to create more complicated compositions in our minds and be able to reflect on through our hands. This is why language is the beginning of abstract thinking. Writing or drawing enables us to store and re-use these thoughts for a longer time. This is applicable significantly in architectural design: by examining the architectural conversation of these two elements of hand and mind, we should analyse sketching as an indication of the occurrence of the design conversation.

Sketching or drawing & visual thinking

The most common technique to enable designing, is sketching. Sketching is a method of thinking (Schön 1983; Goel 1995; Suwa and Tversky 1997; Cross 1999; Tversky 1999; Plimmer and Apperley 2002; Bilda and Demirkan 2003). It is both a reflection of design actions, and the fastest way to visualize the thinking of designers.

Mckim (1980) separates visual thinking into three behaviours: seeing, imagining and drawing. A designer's words do not describe what is already there on the paper but are parallel to the process by which he/she devises and makes what is there. Therefore, drawing and talking are parallel ways of designing, and together make up the *language of designing* (Schön 1991). In other words it is a '*visual language*' of graphics that lacks the essential structure of spoken languages, but can nevertheless be used to communicate (Tversky 2001).

A designer's ability to solve design problems depends on his/her ability to create a virtual world where visual thinking becomes possible and helps to externalize ideas of the different design situations. This design world includes sketches, diagrams, drawings and physical models. By using their preferred methods and materials in a design solving situation, designers create and interact with this world effectively through a *design conversation* (Schön 1991). As such, when a designer uses physical models in a design situation, he/she builds up and interacts with a 3D world (Mitchell 1990) in two modes of thinking: internal and external. This constructed world could limit the designer's vision and cognition of the design situation because of the medium's reflection. In a world of mixed methods and materials, different design worlds develop different types of observation of the real world, thus allowing different reasoning to be made (Mitchell 1990). The design situation depends on what the designer can see and understand. *What if?* is a simple equation set by Schön (1991) to define the design process as follows: 'to *experiment* is to *act* in order to *see* what the *action* leads to'. Although *What if?* is an essential question to carry out any kind of design problem solving task, within individual design processes, mediums and tools. However, each time we ask this question, we explore its possible answer differently to evaluate the result. It carries the nature of being iterative, similar to the design process itself. As a result, we can find many answers through the use of different design methods and mediums. This is the basis for design exploration through different design situations. As a result one can see the reason why this question is not only essential but original, no matter how many times we ask the same question to ourselves through designing.

Schön coined this process 'reflection-in-action' and at the same time refers to the term 'theory-in-use' to describe the nature of the reflective activity engaged in design. By opposing the 'textbook approach' that designers had been taught through education, Schön proposed that by evaluating the design events afterwards (reflection on action), designers would enhance their learning and add new experiences. He believed that it was the ability to reflect both in, and on, action that identified the effective designer from less effective designers. Therefore, *the Reflective Practitioner Model* is an approach to decision-making and problem solving. Schön found that when designers were asked to solve a design task in practice they worked through the problem using a *mixture of knowing and doing*. This *mixture* involves working on the task in hand as well as drawing on previous similar experiences; so they have this process of trying and testing out various possible so-

lutions until they resolve the issue (Schön 1991).

Visual thinking and CAAD

In the same context of Schön's theoretical frame of 'to experiment is to act in order to see what the action leads to', would it be possible to view computers as the latest medium for design conversation? When we look at a CAAD program we should not look at what it does in its technical sense, instead we should look at what it does in its visual sense. Designers are visually oriented and are taught to think graphically (McKim 1972; Laseau, 1980; Do 1998). Visual presentations vary in order to contain the process of design and to communicate both process and outcome (Mitton 1999). For this reason, designers convey their ideas mainly in graphical forms with the benefit that these graphical forms are most effective at accurately conveying their conceptual content to themselves and others. In the context of this ongoing research, CAAD's visualization techniques are the practical methods of encoding data into graphical images to explain a concept via CAAD's medium. Different visual techniques make visual thinking possible and improvable: each concentrate on ways to free the mind from traditional patterns of thought.

Interest in CAAD visualization and its effect on the early design stages has increased as students and designers have reached a different level of awareness in terms of computerized working methods and visual appearance.

As researchers, we should look at whether CAAD changes the way designers think or changes what designers are doing and looking at in their designs. Then we could answer the question of whether CAAD is solely a representation medium or whether it could be a medium for mixed methods and facilitate creativity. We don't look at what they do, we look at whether these programs change the way we think or the way we are doing things. Throughout the development of architectural design mediums, many transitions have occurred, where architects and designers took many years to understand and exploit the new medium potential in conception and the later stages of design evolvement. CAAD as a medium seems to be passing through a similar process of exploiting and understanding. CAAD has passed this stage in the final stages of the architectural design process, in which designers have developed certain strategies to overcome CAAD's potential restrictions. Oxman (2006) mentioned in her paper 'Theory and design in the first digital age' that the digital design process has been translated from its theoretical knowledge into practice.

CAAD program writers' attention in the early days of CAAD development was creating a program to automate the drawing board, not the designing brain, of course. This influence the way we are taught to think about CAAD and how to perceive it. Would it be possible to change this perception and spend more time and effort in exploring it as a new medium for designing? We have to experiment the use of CAAD as a designing tool.

Researchers tried first to involve new trends in CAAD programming to suit the conceptual design stages to enable a sketchy behaviour environment. Researchers have explored the traditional design methods in the invention of new conceptual design tools to aid the designers in creating architectural designs (Do and Gross, 2001) .Our aim is to explore CAAD programs which are already available in our studios and schools of architecture.

However, knowing that sketching is restricted in the CAAD medium (Lawson and Loke, 1997; Verstijnen et al., 1998; Purcell, 1998; Plimmer and Apperley, 2002), this restriction does not justify why designers would not be able to think creatively while using CAAD as a visual thinking tool.

To better understand how CAAD affects and changes the design process, we have to minimize effects of the CAAD medium in terms of: 1- manual & personal presentation skills, 2- architectural design skills, 3- CAAD use skills (Al-Qawasmi, 2004). These variables need to be controlled with a laboratory based condition experiment. Often the triangular shape that they form is distorted by designers' individual skills differences and other cognitive processes. In this research

context, the sample has been taught to use CAAD programs in a generic form to gain the *operative* skills of AutoCAD, ArchiCAD and SketchUp. Asking the sample to use only the CAAD medium in solving a design task at the conceptual phase initiates a shift in their attention slightly from CAAD working methods into architectural designing methods.

The experimental design

An experiment was designed to investigate the conceptual iteration process when designing in the CAAD medium. The study concerned both the teaching method and the use of CAAD during conceptual design, and was completed in two distinct stages.

The first stage was completed using a paper based survey to form an accurate idea of the sample's attitude towards CAAD. Furthermore, that survey reflected how the respondent group had been taught to think of CAAD programs in the studio setting. The second stage was conducting protocol studies involving thinking aloud methods.

Stage 1: evaluation survey

An evaluation survey was conducted with 37 MArch students (Fifth year architecture students). It is appreciated that this sample may not be truly representative of all final year students 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.

Preliminary observations from the survey data showed that, in general, the student sample felt happy with their design skills. They expressed that they use CAAD regularly in the design process. The majority of the sample (54%) uses CAAD in both phases (early phases and final phases) of the design process with 46% using it during the final phase only.

Whilst CAAD has proved to be useful in presenting architectural designs, 55%of the sample also felt that CAAD affects their work *positively* (e.g. in terms of identifying design problems successfully; straighten up the pre-conceptual ideas; communicating and better understanding of their ideas), They felt that it only had a minor impact on things like, understanding the design brief and expressing their design ideas. 67% of the sample reported sketching to be a very important activity to start the design process before moving on to the CAAD medium.

It was reported by the respondent group that CAAD has been presented through teaching and received by students as a computer program ready to accommodate the final version of any design they produce by sketching, physical modelling or other methods. This was reported as being the main reason why students conceive CAAD as a finishing tool to represent their final ideas. While a real world case study (Jonson, 2005) suggests that CAAD programs are capable of aiding the design process of conceptualization, communication and visualization, the survey found that many students view it solely as a finishing tool.

Stage 2: thinking aloud methods in architectural design process

The thinking aloud method allows the researcher to collect qualitative data from individual users. As the name suggests, the user should think aloud while performing a specific design task with a thinking medium. By verbalizing their thoughts, or what they are trying to achieve, we are better able understand how they view the computer system as a designing (thinking) medium. Furthermore, as noted by Gero and Tang (2001) studies using concurrent protocols reveal details of sequences of information processes reflecting the designer's short-term memory. As suggested by Ericsson (2002), the possibility of eliciting valid verbal data from subjects while designing (task performing), depends on the way the researcher instructs them to accomplish the task. Subjects would be encouraged to verbalize without any alteration in the sequence of thoughts. This further support for the data collection methods followed by this research as providing valid data on *thinking*. Concurrent verbalization increases protocol data validity.

As Ericsson reported, the validity of verbal protocol information sequences is increased by reporting thoughts concurrently with minimum time intervals between thought occurrence and its verbal report[1]

The protocol study design

To study the design iteration process, the following experiment series is being conducted, as the central data collection phase of the research. This study uses empirical methodologies, comparing and contrasting two different groups of semi-expert 'designers'. The first designer group reflects a cross section of architectural technology students (4th year) where they have been educated to design by CAAD from the beginning of the design process. The second designer group reflects a cross section of the architectural design students (5th year) where they have been educated to use CAAD at the final stage of the design process.

A straightforward architectural design brief is presented to each respondent who may then select their preferred CAAD program to undertake the design task for one hour. Subjects are asked to verbalize their thoughts during the task while being video-audio taped. The digital camera is arranged to look over the shoulder of the subjects towards his/her computer screen, to minimise the impact on the subject being recorded. The experimenter sits to one side, observing the process and making notes of the design session. Finally, debriefing questions are asked to clear up some of the strategies and other design intentions in relation to their use of CAAD.

The experimental task and medium

The design task involves the creation of an effective gathering space which would unite the university Garthdee campus students, staff and guests in an inspirational environment of art and architecture. A sculpture garden is required for the display of students' art collections and an architectural display area for physical models and electronic images or slides. At the same time it is a relaxing area where students and staff can find lunch meals and hot/cold drinks. The site is a sensitive site that relays in-between the *Scott Sutherland School of Architecture* and *Gray's School of Art*, enjoying the contact with the natural landscaping of the *River Dee* and the grand tree line along the south east edge with a sloping ground towards the river edge. The site was well known by all subjects, and this consequently affected the total time they spent in site inspection. The site is comprised of a moderate slope and restricted by three big trees of an average area of 25m by 15m. An AutoCAD drawing of the site was provided in 2D site plan with a crossed section. The required outcome was a 2D concept and preferably 3D conceptual model while detailed plans, sections, and elevations were optional. Due to its level of complexity, the chosen task had potential to uncover interesting design strategies and a variety of solutions within a limited time frame. The subjects were not allowed to use other mediums to explore their concept, so that we could reveal the difficulties they might face in using CAAD's medium. Although we think of CAAD as a medium that integrates both modes of externalizations; 2D and 3D, in other studies (Bilda and Demirkan, 2003; Bilda, 2001), the switch between two different mediums or modes is considered to be significant data for analysis.

As a warm up exercise, the researcher played a random clip taken from the recording of a pilot study participant. As a demonstration of what they were required to do during the experiment, in terms of the thinking aloud process, the subjects watched the clip for approximately five minutes. The clip showed the experiment setting, the recorded scene and the verbalization content.

Referring to the task in hand, Jin and Chusilp (2006) reported that '*imposing constraints in design leads to more iteration as designer needs to adjust their solution ideas to satisfy multiple constraints*'. This reflects one of the research objectives in applying empirical methodologies in observing and analysing

[1] http://www.psy.fsu.edu/faculty/ericsson/ericsson.proto.thnk.html : April 2005

two groups of semi-experts designers.

Design protocols data & methods

Thinking of the analysis process rises the issue of what sort of data is involved in this architectural design study. This study has collected different design protocols for the same design task. So the design protocols are a medium for two types of information, *constant information* and *variable information*. The constant information proceeds in a linear progression through design and sets a virtual boundary to it. However, at the same time, it configures and forms the design concept. Design task constant information includes the textual information of the design brief, which contains the design requirements of different types of spaces(private, public) , number of spaces, space functions (implicit information of human activities carried out) and the other restrictions (the existing surroundings of buildings ,natural surrounding :trees, landscape, river bank and circulation paths). On the other hand the inconsistent aspect of the protocols information would be the information generated (inferred) during the design session and it varies between individual design protocols as well as the individual thinking styles. The variable information proceeds in a cyclic progression through design and set a physical boundary by other conceptual and functional aspects. As a result, retaining some of the design particulars from the design inferences adds more constraints to protocol's constant information. The conceptual context of the design protocol refers to the variable information of the individual design context.

Transcribing the raw protocols was the first stage towards data analysis, in this process we transcribed the verbalization data provided by the subjects into text with time intervals (Figure1 left). Then we related this part of the protocols to the visual part of the audio/video recordings (Figure 1 right). The separation was not a successful approach to correlate and accumulate the two types of data; verbal and visual. This was reflected in our segmentation scheme by segmenting both: the transcriptions and the drawings into design content of ideas and ideas refinement with its time intervals. Also, by revisiting the raw protocols (recordings and transcriptions) several times we were able to identify which segmentation is the most appropriate for the context of the collected protocols. Each segment refers to one design goal.

Sometimes this change might not occur clearly, but with the visual aid of the videotaped process, the researcher can identify the subject's intention most of the time. As long as the change in intention is clear in the verbal protocol, both the start–end and the type of the segment could be marked.

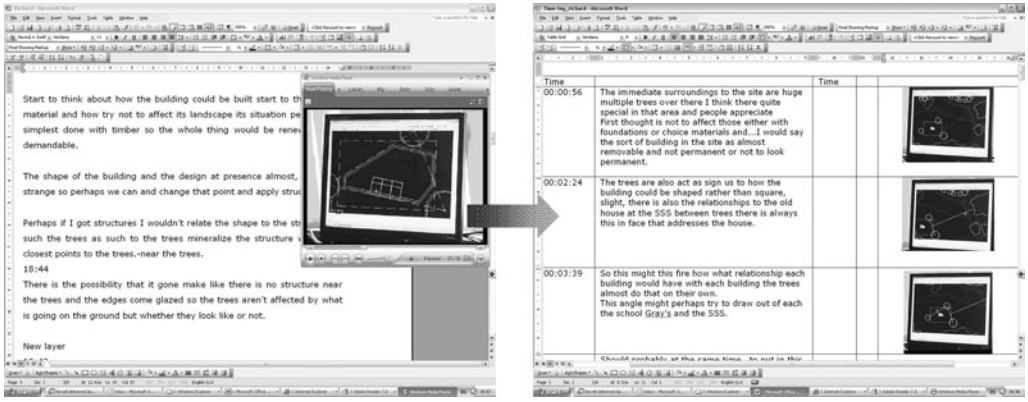


Figure 1
Left: Protocol transcription (text & time intervals).
Right: Protocol transcriptions and visual data clips.

Protocol analysis and models

While the complementary of verbal and visual data makes the analysis more complicated in terms of coding, at the same time it makes the design process more explicit in terms of goals, problem and solutions. The dynamic progression of the video-audio recordings emphasize design conversation, with respect to design process interlinks between the three behaviours of visual thinking: looking, imagining and drawing. Within each activity, designers make decisions about one or more aspects of the problem. However, despite the diversity of design process models in the literature, the next step of our ongoing research is to review and validate those models in terms of our segmented data we have collected and the proposed coding scheme. Design models in general include problem definition/analysis, design synthesis/generation, evaluation and decision making (Rowe 1992; Sanders 1996; Atman et al 2005; Oxman 2006; Jin and Chusilp 2006). Although, Atman et al (2005) code each segment in terms of design step, it is likely to include an explicit - implicit cyclic structure. This iterative process took the shape of a loop in Jin and Chusilp (2006)'s coding scheme. Any loop that ends at unsatisfied result has been neglected; in our study we consider it as an important step to reform the upcoming design events. Approaching a visual/verbal coding scheme with respect to the process-oriented analysis method, is the next objective for the research protocol sessions' analysis.

Protocol discussion & interim results

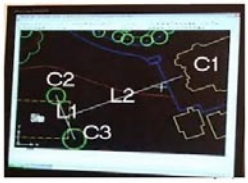
Data analysis of protocol studies is time-intensive and validation of the coding scheme is ongoing. This section presents the observational data of the protocol sessions in using CAAD in terms of time, representations and visual techniques.

The time subjects spent in conceptualization (thinking & drawing) ranged from 40 seconds to 1:30 minutes. This variation reflects two factors: firstly, the uniqueness of individual approaches to conception (Jonson 2005), even when designers are experimenting with a new medium for conceptualization; secondly, the poor level of CAAD general use and 3D modelling in particular (Coyne et al 2002; Jonson 2005) affected the time subjects spent in designing.

The subjects' behaviour in solving the design task shows that the use of conventional techniques and methods in solving a design problem is the basis for the occurrence of design conversation through an iterative conceptual process. As Do et al (2000) report, solving design problems is a conventional process in term of both *design task concerns or intentions*, and certain *graphical symbols* representing certain physical objects. This is still the way designers think about design, even when they are experimenting with a new design world like CAAD. So the digital theory transformation (Oxman 2006) includes the change of medium rather than the methods of visual thinking or the individual way of design thinking, while design cognition is influenced by other factors like designers' spatial visualization abilities and CAAD technical skills.

We focus our attention on the specific representation techniques that they strategically choose not only to generate ideas, but also to guide further design decisions and structure forthcoming design developments. This focus could be the design goals, the changes in design decisions of a design situation, switching modes of thinking (2D and 3D) and different drawing techniques designers used and the conventional designing methods. Below we provide examples to support each of these forms of using visual techniques to organize design elements. Table 1 illustrates segment 2: relating one face of the building (concept) with two of the constraints (two main trees C2, C3 +the old house C1). The constrains position in the site drawing stimulates the designer's thinking to draw a line (L1) between the trees, and another line to experiment its relation with the old house position (C1) and *see* the relation. In other words, to code this under the previous section, L2 was drawn to examine the relation of addressing the old house (C1). L2 acts as the end of the iterative cycle which helped in forming L1 so it acts as a conceptual element for the designer. Because L1, later on,

Table 1
Example of data complement and data coding.

Action time	Verbal data (Subject's verbalization data)	Analysis : segments coding (Subject ID., Segments no. & drawing actions)	Visual data-clips (Constant data & the variable data)
S0:02:24 F0:03:35	(R8 – S2): The trees also act and sign us to how the building could be shaped rather than square, slight, there is also the relationships to the old house at the School between trees there is always this in face that addresses the house.	8.2.1 he draws a line (L1) between the two trees (C2+C3). 8.2.2 he sees the parallel relation with the old house(C1). 8.2.3 draws a line (L2) perpendicular to the old house(C1).	 Clip 8-2 shows the design task constrains (C1,C2 ,C3) and designer's conceptual elements (L1,L2) .

became a design decision, so its code changes to become an added constraint for the designer's conception. So we would code this new element as AC1.

Conclusion

In conclusion we have found that the changing architectural design methodology in both visual thinking and design medium contexts has revealed a need for designers to acquire CAAD skills in an integrated approach. By means of an appropriate teaching, training method and design theory, designers can mediate and promote their visual thinking creatively. The possibility of a complete computer mediated conceptualization process should be acknowledged as a visual thinking tool. Reasoning in design needs a visual means to shape thinking regardless of the medium used.

Despite the speed of CAAD development and the dissemination of CAAD visualisation, we argue that the conventional design methods do not change.

In further it would be interesting if we could uncover the other conceptual phases through the design process where CAAD visualization like 3D modelling and animation are used in respect to the thinking process in solving design.

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