EXPERIMENTING WITH CAAD

As a Means to Solve Conceptual Design by Architecture and Architecture Technology Students

H. SALMAN
The Scott Sutherland School of Architecture and Built Environment, Robert Gordon University, Garthdee Road, Aberdeen AB10 7QB
Email address: h.salman@rgu.ac.uk

Abstract. This study sought to characterise students' design activity while designing with Computer Aided Design (CAAD) professional programs and its impact on the students' design process. The design protocol participants were final year students (architectural design and architectural technology), who have spent at least four years in a school of architecture and were confident CAAD users. The analysis represents four *CAAD-based protocols* of final year students at a school of architecture. The analysed protocols varied in more than one aspect. This variation includes: (1) programs, (2) the mode of using programs whether single or multiple, (3) protocol segments (total number, duration and frequencies), and (4) design categories and total time spent in designing. In light of the study results, the participants demonstrated that, for the same design problem, restraining the conceptual design medium would not necessarily bind them to a certain design strategy. However, there are some disciplinary differences between AD and AT final year students, on how CAAD is used during to solve conceptual design.

1. Background

As a result of how Computer Aided Architectural Design (CAAD) programs was perceived in architectural design, as opposed to other disciplines, the understanding of its impact on design practice and education is still fragmented (Al-Qawasmi 2005; Salman 2004, 2011; Salman et al 2008). However, some attempts are being made by theorists (Oxman 2006, 2008) and studio instructors (Al-Qawasmi 2004, 2005; Lu 2008; Reffat 2006, 2007), to change how CAAD is perceived through practical engagement rather than making predictions of how inappropriate CAAD is for designing. Experimenting through CAAD active studies within a studio setting, whether traditional or digital, is the way forward in understanding CAAD as a new medium rather than a medium that mimics what designers have been practicing since the 1960s. A pragmatic investigation into the influence of digital mediums on design and its aspects is required (Salman et.al. 2014). However, technology affects and changes architectural practice but the designer is the most valuable part of the design process.

At the present time, it is apparent that both, architectural and architectural technology students finalise their conceptual design using CAAD software programs as a *presentational* mode of thinking (Ataman 2000; Al-Qawasmi 2004, 2005). By creating these presentations, a student's main endeavour is to convey design ideas as well as to attract the reviewers' (tutors') attention and their positive appraisal. This could be one reason for using CAAD, but on the other hand, it could be related to the ability and support that CAAD provides in the conception process of design. However, this *representational* mode of thinking has a hidden side and it is the rationale behind the creation process of these presentations that this study aims to look into. Therefore, this study frames representation as a tool for discovery at phases of conceptualisation rather than the final product of the same creative process.

Apparently the educational curriculum has distinguished both professions, Architectural Design and Architectural Technology, by how CAAD is integrated within its core knowledge and CAAD's role in different phases of the studio design project. Considering the continuous technological improvements one can see that the younger profession (like AT) has taken the characteristics of digital thinking and production; however, this has to be accompanied with appropriate theoretical underpinnings.

Some effects to consider in perceiving a new CAAD status in education are: the highly positive interaction between students and computers; the embrace of CAAD's efficiency in architectural practices in relation to productivity and speed of completion; the relationship between CAAD and the skill set of the contemporary graduate that is required for employability and future competency; the implication of the studio model and tutor's attitude toward CAAD; the emergence of digital design and prefabrication, and Building Information Modelling (BIM).

1.1. RESEARCH AIM AND OBJECTIVES

The main motive for this study was to explore the potential effect of CAAD on the conceptual phase of design. This is important to overcome the transitional gap of design media in architectural design processes (Salman 2004). Most of the work that has been done on CAAD is based on theoretical assumptions. This paper aims to explore empirically some of these assumptions. The study objectives are:

- to provide an understanding of students' design process while designing with CAAD representations, and the impact of this on the individual design process of both Architectural Design students and Architectural Technology students, and
- to see the analytical differences between Architectural Design and Architectural Technology design processes when using the process oriented coding scheme (Gero and McNeill 1998, 1995; McNeill and Edmonds 1994; Purcell et al. 1996) for coding the design process, level of abstraction, external representations and explicit strategies.

1.2. CAAD AND EXPERIMENTATION

The term *design workspace* refers to the tools and media that are available to students in a shared workspace (studio), such as pen and paper or CAAD software programs, and students' interpersonal communication channels (reflection). Presumably, students can move freely between both spaces. In the studio, one can observe both interpersonal interactions between students and their tutors, and their interaction with the various workspace tools and media. These interactions are responsible for giving the design workspace its richness and complexity. The flow of media may change to accommodate a learning goal or a systematic approach to design exploration (c.f. Zuo, et al 2010). Media flow at the studio suggests that it has a pedagogical significance that is mostly guided by the project model, the stage and the project size. However, sketching and physical modelling are the prevalent and the most appraised by studio instructors (Basa and Şenyapili 2005; RIBA Report 2005).

Within the traditional context of design media and architectural design and Architectural technology education, there is *cooperation* between students and studio workspace. One of these workspace tools is CAAD. This cooperation is recognised, accepted and accredited under one condition: the role CAAD plays in the design process. A role is accepted in architectural education if CAAD is used for drafting and presentation, and not accepted if CAAD is used for conception or design exploration, and experimentation. Thus, conditions are formed under the following situations: how CAAD is being used, what CAAD is being used for, and when CAAD is being used.

2. Methodology

Researchers have used *Thinking Aloud Methods* in the architectural design process to theorise and present the rational structure of the design process. The thinking aloud method allows the researcher to collect qualitative data from individual users. As the name suggests, the subject should think aloud while performing a specific design task within a medium. These could be paper drawings (Schön and Wiggins 1992), (Bilda and Demirkan 2003), mental imagery (Bilda 2006), or physical modelling. Moreover, van Someren, Barnard and Sandberg (1994) state that "*thinking aloud takes place concurrently with the cognitive process."* By verbalising their thoughts, or what they are trying to achieve, data emerges to help the researcher understand how they solve the design problem in that designing medium. So the verbalisation acts as a narration of the design process and the subject's behaviour. This method result is also known as "concurrent protocol" (Tang 2001, Ericsson and Simon 1993; van Someren, Barnard and Sandberg 1994). Furthermore, as noted by Gero and Tang (2001), using concurrent protocols reveals details of sequences of information processes reflecting the designer's short-term memory. Therefore, concurrent protocols (verbalisation) reveal the process of design (Dorst and Dijkhuis 1996). This research design is based on the work of Gero and McNeill (1998), Bilda (2001, 2006), Bilda and Demirkan (2003), Akin and Lin (1995) and Goldschmidt (1996), whereby a theoretical framework is outlined to achieve the study objectives. Protocol study analysis enables the understanding of how participants arrived at the proposed design, what sorts of difficulties they faced and how they managed the design brief constraints.

2.1 EXPERIMENT DESIGN

It is recognised that the design situation is influenced by the design task (brief) at hand and the design medium (Coyne, et al 2002). These two aspects of *design* problem solving set the constraints for the proposed design task. The participant would have to compromise between the design task constraints and the medium constraints.

To generate CAAD-based design protocols, an architectural design brief is presented to participants who then select their preferred CAAD to attempt the design task. Participants were asked to verbalise their thoughts during the task while being video and audio taped.

2.1.1 Experiment setting

The experimental setting is shown in Figure 1, the digital camera is arranged to look over the right shoulder of the participants towards the computer screen, to minimise the impact on the participant being recorded (Van Someren, et al 1994; Bilda 2006). The researcher sits to one side, observing the process and making notes of the design session.

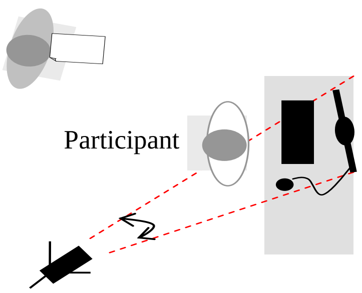

Figure 1. The experiment setting

2.1.2 Procedure

Each participant went through a sequence of steps, starting with a brief explanation about the experiment. Each participant was required to design a gathering space for students within the given site while using one or more CAAD programs within the design session lasting approximately 60 minutes. All participants stopped when they felt that they were satisfied with their proposal. Finally, this was followed by a debriefing session which lasted for about 30 minutes. Accordingly, four protocols were selected and prepared for analysis.

2.2.4. Protocols Analysis

In the context of protocol studies, transcription, segmentation and encoding are three necessary procedural steps for analysis. Therefore, the segmented protocols can be treated as raw data and the coded protocols as data (Van Someren, et al 1994). The transition from raw data to data requires two main activities: dividing the protocol transcription (verbal and visual) into segments, and encoding what is going on in a segment of activities, i.e. codes.

In this study each segment is coded with one code. The distribution of design codes over time gives a more coherent understanding of the design process, and explains why a certain action is dominant in relation to a certain phase(s) of the process in relation to design .

2.2.5. Protocol coding schemes

The design session segments were coded using the process oriented coding scheme (Gero and McNeill 1998, 1995; McNeill and Edmonds 1994; Purcell et al. 1996) for coding the design process, level of abstraction, external representations and explicit strategies. Every segment was coded with one design process code, and multiple external representations upon its occurrences. Then the codes were studied qualitatively and quantitatively. Through calculating and documenting the total time spent in each code of the coding schemes. Hence, the total time for each segment can be detected and compared throughout the four protocols. As such, the duration data was helpful in identifying how much time each student allocated to each strategy, and what sort of design strategy the student used most frequently.

3. Results

Four male students with an average age of 22 years (SD .81650) spent an average duration of 00:59:51 min on the design task. At the time of analysis, the first two students were studying Architectural Design for a Master of Architecture and were labelled in the study as AD1 and AD2. The other selected two protocols were final year Architectural Technology students, and were labelled in the study as AT1 and AT2.

3.1. PROTOCOLS DESCRIPTION

In this study, three of the analysed protocols were classified as *single program-based protocol*s, as the participants AD1, AT1 and AT2 used *either* AutoCAD, or SketchUp, exclusively. The fourth selected protocol was a *multi program-based design* in which the participant AD2 started the design with AutoCAD (33% of the total design duration) and switched to SketchUp (67% of the total design duration). Both types of selected protocols can be seen in Figure 2 in relation to the program used.

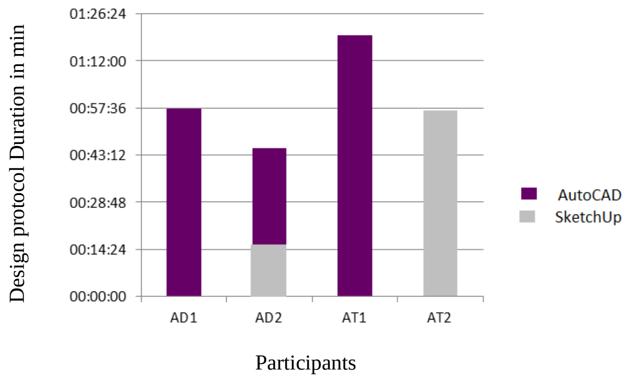

Figure ***2.*** Program(s) and design protocols duration for each participant

Two protocols of the *single* protocol have chosen AutoCAD to complete the task. This may suggest that final year students are: (1) skilful in one program, although they have access to many other programs, and (2) more confident in using one program (AutoCAD) to design in 2D and 3D rather than using multiple programs. A similar observation was previously made by Garcia et al (2007), when students preferred to learn and use AutoCAD although it was more difficult to learn from the other options. Students preferred AutoCAD for two reasons: its advanced technical aspects and its role in their future career (Garcia et al 2007). This also reflects the common perspective of why these professional systems are important in design schools and design teaching.

3.2. MODE OF ENGAGEMENT

The engagement mode was classified into 2D, 2D/3D and 3D, as shown in figure 3. Two participants (AD1 and AT1) spent more time designing in 2D mode and less time designing in 3D mode. The design approach of these students can be seen as a 2D based CAAD approach. On the other hand, participant AT2 spent most of the time designing in 3D mode, which can be seen as a 3D based CAAD approach, with AD2 being classified as a 2D/3D based CAAD approach.

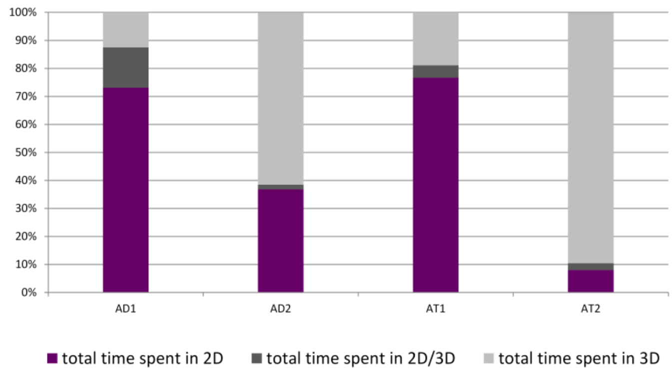

Figure 3. Design engagement in 2D and 3D.

3.3. DESCRIPTIVE STATISTICS OF THE DESIGN PROTOCOLS

A segment is the smallest unit of the design process that can be assessed and measured in parallel to its description: total number, length (duration) and coding (content). Moreover, the total number of segments roughly reflects the number of design intentions of one design session; segment duration reflects the shift of intention, and the student's speed of design thought (decision making); and coding reflects the content of a segment in terms of problem solving behaviour and engagement. The total number of segments varied between the four protocols (69-83 segments). The average number of segments for the four design sessions is 74.75 segments.

3.3.1. Duration of Segments

The mean segment length for all protocols ranged from 32 seconds to 1.02 minutes, with a minimum segment duration of 4 seconds, and a maximum segment duration of 3.12 minutes, shown in Figure 5.

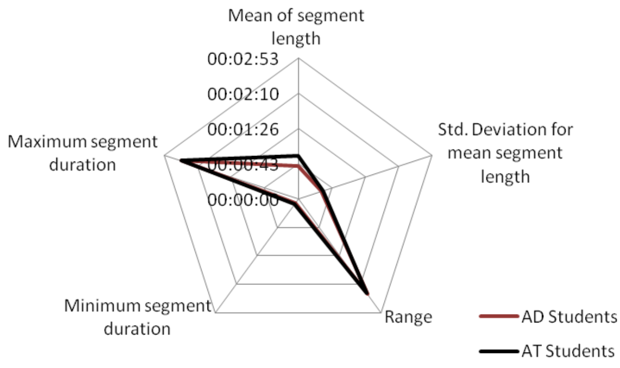

Figure 4 Descriptive statistics of the four design protocols.

The total number of segments was relatively low with higher durations, suggesting that CAAD protocols have relatively longer shifts compared to sketching protocol studies. One protocol which showed a different behaviour in terms of these measures, was a CAAD multi design (AD2) protocol

Another interesting feature of the conceptual design process was the frequency of shifts. In general, AD students showed a faster pace in their number of transitions when compared to AT students, as shown in figure 4.

3.3.2. Number of transitions

The change in design intention from one segment to another shows how many transitions the participant made during the design process. The number of transitions is a measure of the number of times a participant moved from one design activity to another (Adams et al 2006; Atman et al 1999).

Thus, the number of transitions was counted in 10 minute intervals to describe the richness of a design phase whereby the number of transitions - from one segment to another segment is counted to describe the phase's extensiveness of codes. The chart, in Figure 5, illustrates the average number of transitions for every interval.

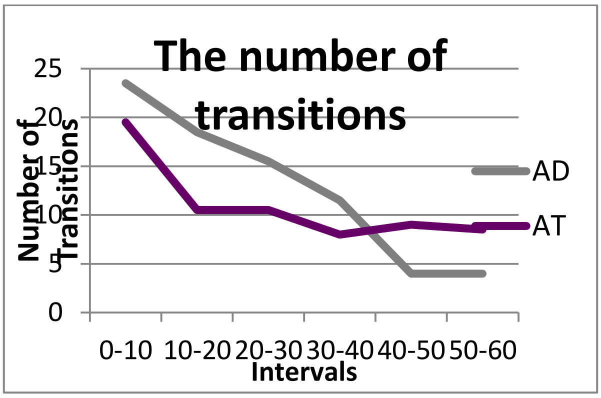

Figure 5 The number of transitions in every 10 minutes for the four participants.

All protocols indicated a similarity in the first and last intervals of the design process phases as they had the highest number of transition at the early phase compared to the last phase. However, the progression from the early phase to the last phase was not similar as it revealed two main trends. The first was hierarchical, whereby Architectural Design students (AD1 and AD2) transitions rate in every interval had a lower rate from the preceding interval. Architectural Technology students show a different trend whereby the transitions rate collapsed below the rate of the succeeding interval. The rate was hierarchical for the first four intervals followed by an increment. The amount of transitions increased in the last two phases of the design process.

These results show that the transition rate varied upon the phase of the design process whether occurring at the early phases of the design or later phases. In addition, it showed that the speed of thought had decreased during the later phases, with the exception of one AT student.

3.4. DESIGN PROCESS CODING

The design strategies for all participants, shown in Figure 6, present the general categories of the design process micro strategies (Gero and McNeill 1998). All the participants, AD and AT, bear a resemblance in the general categorical percentages of the total time spent on a certain category.

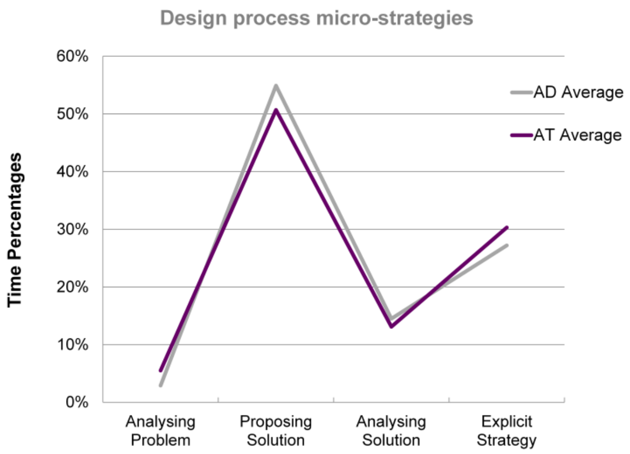

Figure 6. Design process micro-strategies as a percentage of the elapsed time.

The results show that of their protocol duration was spent on *proposing a design solution* (55% and 51%), spending 15% and 12%, respectively, of that duration on analysing the design solution, with only 3% and 6% respectively, of the duration spent on analysing the design problem. However, more than a quarter (27 and 30% respectively) of the design protocol was spent on explicit strategies as they are concerned with codes other than the design process, that is working strategy, planning, difficulties and problems. However, the differences were minor, as it shows that AD students spent slightly more of their design duration on finding ideas, whereas AT students were more concerned with the technical failures of CAAD during design.

Having said that, the detailed analysis of the design micro strategies demonstrated the many differences that each student exhibited during the design session.

3.4.2. Level of abstraction

The results of calculating the total time that a participant spends in designing in relation to the five levels of abstraction (Gero and McNeill 1998; Salman 2011) is presented in percentages. Figure 7 shows how much time AD and AT students spent on every level of abstraction as a percentage of the whole duration.

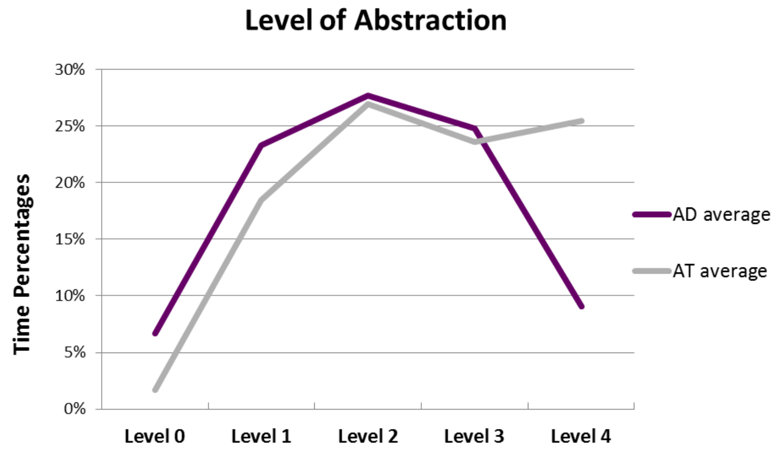

Figure 7 The average levels of abstraction that AD and AT students

On average, all students spent most of the design session time considering the design problem at levels 1, 2 and 3, with a considerable amount of time on level 4, while spending the least time on level 0. AD and AT students spent minimal time on considering the design problem on level 0, however AD students spent a higher percentage of time of their design process considering the design on level 0. Also, AD students spent a higher percentage of time considering the design on level 4 compared to AT students who proved to be more engaged in CAAD technical consideration at level 4.

One way is to contextualise these differences in the light of the students' design micro strategies as it shows that all students spent a lower percentage of time on analysing the problem, which pertains to the design situation (design brief). The other part of the design situation is CAAD's external representations which influenced the shift of focus that is while considering the design at level 0, CAAD urges them to draw and advance in drawing. While they are considering the design at level 1, they are also reflecting on level 0 while physically engaged in level 1, 2 or 3. Proposing a solution through drawing characterises the novice design process is used more than any other strategy. The little amount of time that participants spent considering level 0 suggests that CAAD's level of detail (Level 4) has shifted the participant's design focus primarily from level 0 (whole) to consider the more detailed levels.

3.4.3. External representation occurrences

The Protocol Study further investigated how design representational activities supported individual design processes in designing. The representations coding scheme was used to capture the multi-mode activity of CAAD representation and its relation to the main design micro strategies. Mapping the micro representation strategies shows how and when these were used as the main source for visual information in relation to what design micro strategies were used during the session. While drawing was the main focus of problem solving, documenting the use of other types of external representation was important, such as verbal ideas, which are ideas mentioned with no visual support or documentation, gesture and referring to a drawing or inspecting a drawing with a cursor or hand.

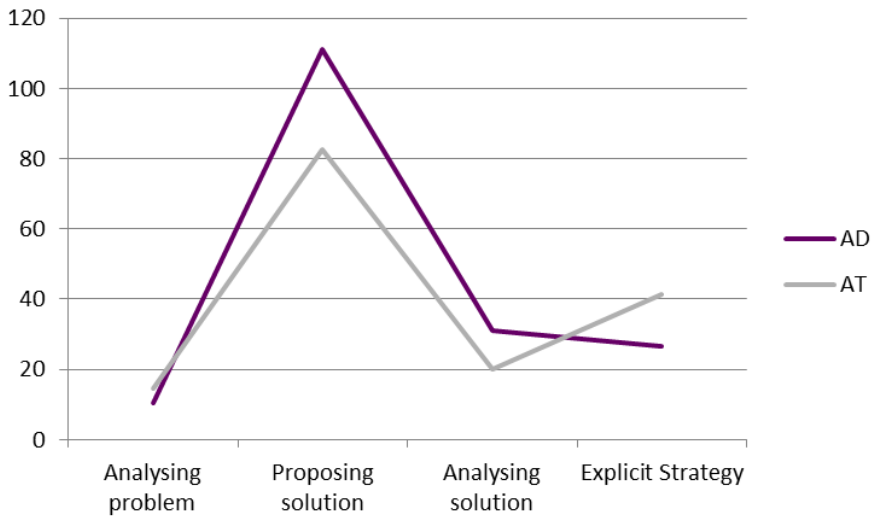

Figure 8 The matrices between external representations and design strategies.

While the student is engaged in one design micro strategy, he is also engaged in a multiple mode of external representation; therefore, each segment is coded with at least two external representation codes. For this reason, a matrix was sought to reveal the relationship between the occurrences of external representations in relation to design strategies. The matrices of the four protocols are presented in Figure 8. Each point shows the number of occurrences of external representation in relation to design strategy.

The students used most of the external representation codes, however proposing a solution occurred with the most common external representations, which were: (1) create (mainly creating new drawing, or by adding to a drawing, continuing on a previous drawing and moving parts to make another composition) and (2) modify (modify by variables, 3D or by moving parts). These were followed by copy, inspect, refer and verbal ideas.

Analysing the problem was intersected with the lowest number of external representations in all protocols. However, AD students had the highest occurrence of external representations when they were engaged in proposing and analysing their design solutions because they had been mostly engaged in graphical analysis.

On the other hand, explicit strategy (EX) intersected with various external representation activities, which refers also to the verbalising style of the participants. The most frequent occurrences were observed AT protocols, shown in Figure 8. This is mainly because of their verbalising style as they described CAAD strategy in drawing things. This shows that even when the student deviates from the design strategies by explicitly describing a difficulty in CAAD or how things should be, they are also engaged in a physical representation activity.

It is obvious that while students are engaged in externalising and reflecting on CAAD representations, they are also using other types of external representations with lower levels of certainty and this might help to overcome the complexity of CAAD compared to other types of externalisation.

4. Discussion & Conclusions

Although three of the participants were able to produce a conceptual proposition in less than an hour, the average segment length (sec/min) in relation to the design intention as the basis of segmentation showed that CAAD, as a medium, has affected the design process, as participants needed more time to actually do what they intended to do. This result confirms the findings of Bilda and Demirkan (2003) that designing with a digital media compared to a traditional media is a time consuming process.

Another observation was the software nature and its visual feedback. The student (AD2) who switched from one program to another was more likely to experience sudden discoveries (new visual insights) than other students. However, this also pertains to other factors such as the mode of visual interaction (2D or 3D), the strategic proceeding from 2D towards 3D, that is the sequence of the student's conceptual progression from 2D spatial diagrams to 3D construction, and finally the software nature, for example subtracting geometrical volumes in SketchUp while drawing an intersecting 3D object (Boolean operations). Design experimenting is facilitated by these actions: moving the drawn objects/shapes to see the new spatial relations within the configuration and by moving things around in CAAD to see the "what if" consequence on decision-making. Most of the ideas were mentioned before actually drawing its visual resemblance in CAAD.

Another observation was the methods that were used by the students. For example, AT students were more likely to confront and retract some of the decisions that they had made earlier and solve them on the level of 2D. This student showed many differences in thinking, design process and using CAAD.

Three of the four participants in this study have spent less time (fewer numbers of segments) in analysing the problem than proposing or analysing a solution. This can be related to the clarity of the site drawing in 2D CAAD that enabled them to extract any information needed as they were designing in context.

Levels of abstraction coding reflects less changes in its pattern compared to other codings and compared to design process micro strategies and external representation. The student focus span in considering one level of abstraction is longer than the change of design micro strategies as well as for external representation change. A similar trend was observed in Gero and McNeill's (1998) study of sketching protocol.

The participants spent minimal time considering their design on level 0, suggesting that the number of segments that participants spent in analysing the design situation before starting to set their conceptual proposition, was small. On the contrary, AT students spent relatively more time considering level 4, to suggest that the level of CAAD detail has occasionally shifted the student's focus, primarily in considering the more detailed levels of abstraction, that is considering finer details of the drawn elements or the material used, or correcting some of the technical faults.

In concluding this study, two points are considered: the collected design protocols represent "designing…as a time sequence of activities" (Gero and McNeill 1998), and as a constantly evolving conceptual structure or construct. Similarly, the participating students were able to create and maintain a representation of the design world where design ideas can be developed, to be described as co-operative behaviour with CAAD representations.

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