The impact of CAAD on Design Methodology and Visual Thinking in Architectural Education

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Abstract

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This thesis aims to explore the potential impact of Computer Aided Architectural Design (CAAD) as a conceptual design tool on the design methodology of final year students. Many design studies have focused on sketching and its relationship with creative thinking to validate CAAD programs as a design tool. On the contrary, this study argues that the continued primacy of traditional tools as the predominant conceptual tools needs more evidence in the contemporary design practices. That is to say, the relative importance of CAAD alongside other media, such as sketching, model making and verbalisation must be recognised before the forthcoming leap in CAAD programs development.

To illustrate these ideas, the Scott Sutherland School of Architecture and Built Environment was used as a case study to explore CAAD's role in the educational context, the studio in general and the final year studio in particular. A mixed methods approach was employed to carry out two studies: a case study and a protocol study. A case study approach was utilised to understand the modern context whereby CAAD is used by the students despite CAAD not being an integrated part of the project model. The case study was also used to document the reasons behind students' tendency of using CAAD at the conceptual phases of the design process. Mixed methods were used to collect data at three different intervals of the two semesters; before starting the studio project, while working on the project and after submitting the final project. The methods used include a questionnaire survey, structured reflection interviews, and a focus group.

A protocol study was conducted to understand the impact of CAAD on self-communication using the think aloud method under the same experimental conditions using CAAD program(s) as the only external representation. The case study findings clarified the effects of the traditional context of the studio and the project model on CAAD's utility within students' design processes and identified the lack of CAAD professional skills, and the integration of CAAD as a knowledge base. The protocol study findings provided a greater understanding of the cognitive processes in designing and design performance while using CAAD, as well as acknowledging the possibility of a cyclic conceptual process. The potential impact of CAAD on the design process was further categorised.

The empirical exploration provides CAAD research with new insights, instigating more useful ways of teaching and learning by an appropriate integration of CAAD programs and design methods in a situated manner where students can enhance their design processes creatively. It is proposed that a more measured and disinterested approach is now required to investigate CAAD and their implications for education.

Keywords: Design process, CAAD, Design media, Media impact, Protocol study, Final year architecture students, Project model.

Declaration

The candidate has not, while registered for this Ph.D. submission, been registered for another award at a university during the research programme.

None of the original material in this thesis has been used in any other submission for an academic award. Acknowledgements for assistance received are given under the heading acknowledgements and any excerpts from other work have been acknowledged by its source and author.

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Public Outputs Related To This Research

SALMAN, H. S., LAING, R., and CONNIFF A., 2008. The Changing Role of CAAD in the Architectural Design Studio. *The Built and Human Environment Review* [Online], 1. pp. 25-39. Available from: http://www.tbher.org/index.php/bher/article/view/5/3

SALMAN, H. S., 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,* Volos (Greece) 6-9 September 2006, pp. 700-708.

SALMAN H. S., LAING R. and CONNIFF A., 2007. *The changing role(s) of CAAD at the architectural design studio, The 4th International Built and Human Environment Research Week and the Seventh International Postgraduate Research Conference*. 26-30 March 2007. Salford: University of Salford.

SALMAN, H. S. , 2005. *CAAD as a Design Medium in the Conceptual Phase of the Architectural Design Process. Postgraduate Conference,* University of Aberdeen. Aberdeen, Scotland.

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GLOSSARY

Abbreviation

2D	Two-dimensional model/modelling/representation.
3D	Three-dimensional model/modelling/ representation.
CAD or CAAD	"computer aided design, means designing with the aid of a computer. Therefore definition contains only the means to design and process images, not all possible tools that information technology allows" (Haapasalo 2000).

Terms

Abstraction	a general concept formed by extracting common features from specific examples.
Analog media, Conventional or traditional	involves the manual use of material such as paper, vellum, graphite, balsa wood, cardboard and ink (Bermudez and King 2000).
Behaviour / design behaviour	the way or the manner by which a person (student, designer) behaves toward a design situation or under different conditions
Cohort	a group of students that are closely related to course of study, stage and at the same level in terms of the course structure.
Cognition	the term 'cognition' is intended to embrace all those processes of perception, attention, interpretation, pattern recognition, analysis, memory, understanding and inventiveness that go to make up human consciousness and intelligence. (Baynes and Roberts, 1984, pp. 8–9)
Cognitive activity	design is an iterative process where emerging ideas are studied, explored, revised and improved until a solution is recognized.
Design activity	project based design work undertaken within the design studio environment.
Design medium	a hosting environment for the interactive process of conceptualisation, visualisation, and expression carried out through
Design process	*a framework can be brought to the design process by considering the designer's activity as consisting of a sequence of actions or micro strategies each typically lasting for a few seconds or tens of seconds. The design process can be viewed as one in which the designer engages the*

	design problem by calling upon a repertoire of micro strategies.(Gero and McNeill 1998).
Design skills	these skills relating to the acquisition of, and ability to apply a design process to a range of scenarios and conditions.
Design studio	a learning setting in which architectural design is learned and characterised by a socially interactive environment in which drawing, modelling and discourse takes place.
Dynamic	refers to the use of knowledge and representations, in contrast to their content. (Visser 2006).
Micro level	is the focus of a design activity on self communication. For example, the conversation between a designer and a design situation.
Macro level	is focused on design activities within a social context considering a project under more than one factor.
Task	refers to, either what people are supposed to do (prescribed task), or the task that they set themselves and which they carry out (actual task). (Visser 2006).
Representation	is framed as "an instrument of invention which is not an end product but an active component at phases of ideation, conceptualisation, experimentation and visualisation in the creative design process." (Reinhardt 2008).

1 Introduction to the Thesis

Computers have contributed to architectural design by providing tools for drafting, presentation and databases. Researchers have argued that this contribution is significant, as a presentation tool, in the final phases of the design process. As computer modelling allows designers to think about the designed object(s), this enables designers to concentrate on decisions about objects rather than drawings. This is much closer to Computer Aided Architectural Design (CAAD), as opposed to Computer Aided Drafting. Although the terms CAD (computer aided design and/or drafting) and CAAD (computer aided architectural design and/or drafting) are often used interchangeably in design studies, CAD is generally considered to be a more generic term than CAAD.

At the present time, it is apparent that architectural students finalise their conceptual design propositions using one or more 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 (and assessment). 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 thesis aims to look into.

It is of interest to know how these representations are created at the early phases of design and what the conceptual process is 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 different visual thinking media and merely presented by CAAD programs? This research particularly focuses on the situation whereby a designer (student) chooses to use CAAD media as a conceptual tool in the early phases of design.

As a result of how CAAD 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). However, some attempts are being made by theorists (Oxman 2006, 2008) and studio instructors (Al-Qawasmi 2004, 2005; Lu 2008), 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 media rather than a media that mimics what designers (methods) have been practicing since the 1960s. A pragmatic investigation into the influence of digital media on design and its aspects is required. However, technology affects and changes architectural practice but the designer is the most valuable part of the design process.

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 architect that is required for employability and future competency; the implication of the studio model and tutor's attitude toward CAAD as part of the project model in CAAD future practice; and, the emergence of digital design theory.

The study of CAAD evolution showed that CAAD development was not linear. In reflecting on various perspectives and philosophies, therefore, CAAD has been, and remains one of the important variables affecting architectural design theory, processes and methods.

1.1 The Research Problem: CAAD in the Conceptual Design Process

The main motive for this thesis is to explore the potential of CAAD as a conceptual design tool to overcome the transitional gap of design media in architectural design (Salman 2004). Most of the work that has been done on CAAD is based on theoretical assumptions and this thesis aims to explore empirically some aspects of these studies. Moreover, this research looks at CAAD's role in the educational context, the traditional studio in general and the final year studio in particular.

Within the traditional context of design media and architectural design education, there is cooperation between students and studio workspace (tools). 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 -

conception. A role is accepted if CAAD is used for drafting and presentation (production), and not accepted if CAAD is used for conception or design exploration. 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.

After 50 years of CAAD evolution and existence, are educators going to be satisfied with that role, are they planning to change that, taking into perspective the rapid changes in technology and the socio-culture aspects of students' life as well as architectural practice? In recent years CAAD has been highlighted as a socio- cultural matter rather than "*merely a technical issue*" (Pektas and Erkip 2006; Tweed 2000).The emergence of digital design as a new theory is being mooted by leading architects such as Frank Gehry, Zaha Hadid, Greg Lynn, Ben van Berkel, Peter Eisenman and theorists such as Kalay (2004) and Oxman (2006, 2008) who are all predicting new design approaches, methods and processes. How is academia going to cope with such a challenge when CAAD's role is still being debated? CAAD is becoming a knowledge base rather than a tool or a presentation. CAAD teaching must embrace CAAD as a design tool to enable students and graduates to acquire the deeper structures of this knowledge base. It is the knowledge behind the tool that counts and this should be considered in education.

As a result of how digital media has been perceived in architecture as opposed to other disciplines, the understanding of its impact on design practice and education is still fragmented (Al-Qawasmi 2005). However, some attempts have been made by theorists (Oxman 2006, 2008) and studio instructors (Al-Qawasmi 2004, 2005) to bridge this gap of understanding. One way is to investigate CAAD as a different rather than a comparable media to sketching. For example, using these systems at the conceptual phase was influenced by the perception of their users (students, practitioners and tutors), which was mostly based on and compared to an automated drawing board.

In order for CAAD to be explored properly, there needs to be recognition that modern CAAD systems offer significant opportunities within architectural practice. What is needed is pragmatic investigation of the influence of digital media on design in an educational setting which is focused on the learning outcome.

1.2 Aim and Objectives

This thesis aims to understand the current role of CAAD in architectural design education of final year students on two levels of their design activity: on the macro level of interaction among students, their tools and project models in the studio context; and on the micro level of interaction among the student, CAAD, and design brief in the individual design process. It will also investigate what CAAD can add to the conceptual design process that other tools (representations) cannot, and how CAAD might improve design or impact design.

This thesis will therefore look at the interaction between students' problem solving (implicit thinking) and CAAD externalisation (explicit thinking). Analysing these kinds of design representations will identify new forms of interaction between mental and visual thinking and pose the following question: if students use CAAD in the design process, will there be any difference in design performance compared to other representations?

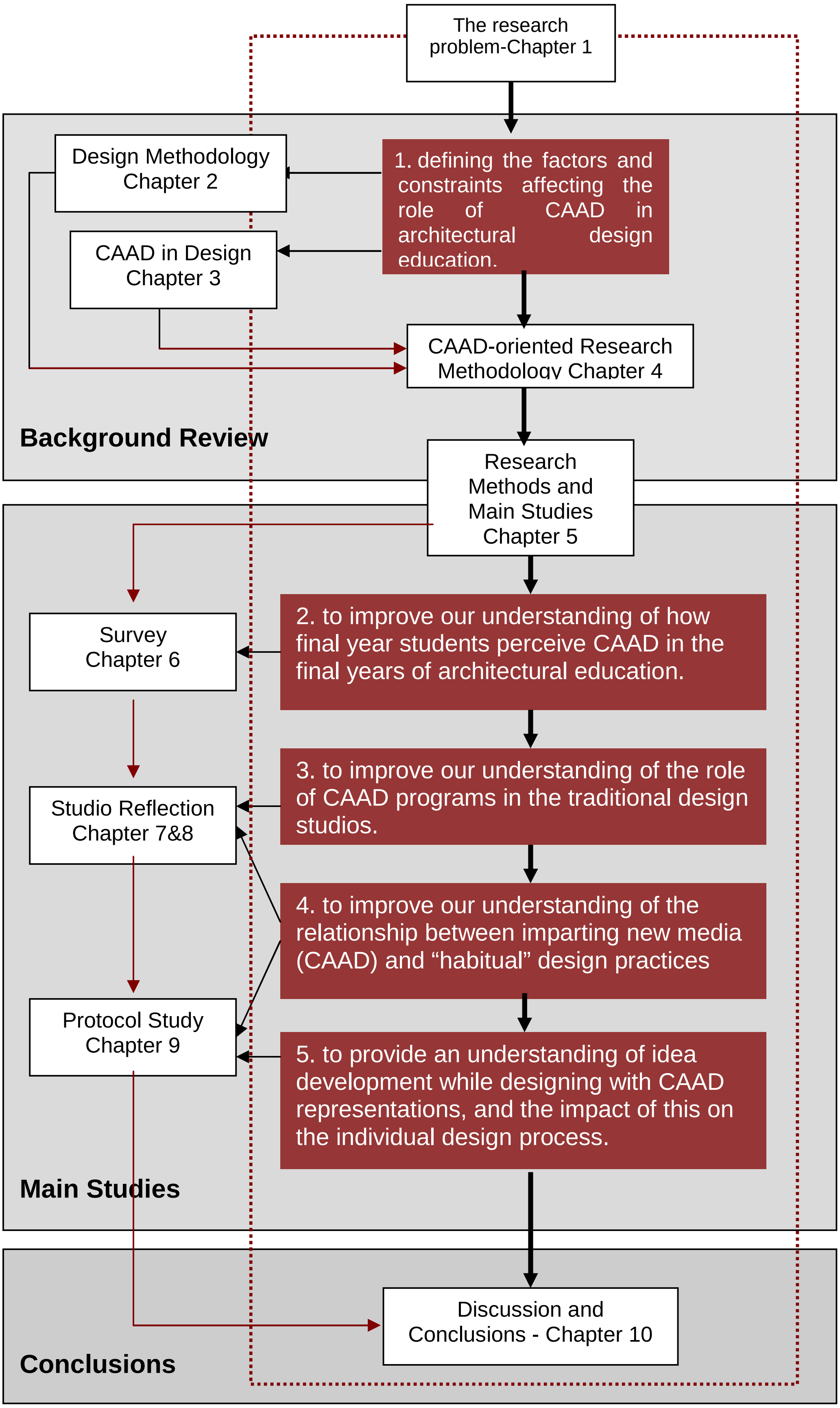
The study objectives are situated within the context of final year architectural education and CAAD's professional systems that are used in most schools of architecture and architectural practice, e.g. AutoCAD and SketchUp. The study objectives below are illustrated in Figure 1-1 to show the relationship with thesis content:

1- Defining the factors and constraints affecting the role of CAAD in architectural design education.
2- To improve our understanding of how final year students perceive CAAD in the later years of their education and the role of CAAD educational methods in the way CAAD is used by final year students.
3- To improve our understanding of the role of CAAD programs in the traditional design studio.
4- To improve our understanding of the relationship between imparting new media CAAD skills and "habitual" design practices.
5- To provide an understanding of idea development while designing with CAAD representations with respect to CAAD's (current) characteristics as a representational medium, and the impact of this on individual design process.

These objectives are also elaborated on in chapter five. An inquiry within the context in which *knowing-in-action* (Schön, 1983) is operating, provides a better understanding of how students' skill differences (i.e. architectural design, sketching, CAAD skills) and design media preferences are balanced and used in context. These objectives are achieved through documenting the student's design activity (process) on two levels: the students design process within a studio context, and the student's individual design activity (reflection in action).

In general, this research will benefit students in the first instance by proposing a development cycle to evaluate their CAAD skills. This research will change or elevate students' usage of CAAD representations (drawings) from detailed and presentational into analytical representations that are experimental, explorative and enjoyable. In addition to this for students, access to the findings of this research will benefit the teaching community by providing practical evidence in relation to CAAD impact and reject some of the theoretical assertions that have been debated in the literature for many years. As a result, an understanding of the role of CAAD educational methods and its utilisation in conceptual design will be improved during the early phases of design.

Figure 1-1 The thesis objectives and structure.



1.3 Research Approach

A great majority of views expressed in the literature are based on the validation of CAAD programs on the basis of them replacing traditional tools such as sketching, hand drawing and physical modelling. In contrast, this research examines the practical consequences of design media on the theoretical issues of visual thinking, conception and drawing. Thus, "*pragmatism*" is the doctrine for this thesis approach which as stated by Cresswell (2009 p.11) provides "*multiple methods, different world views, and different assumptions, as well as to different forms of data collection and analysis in the mixed methods study*".

For the most part, this examination was carried out via two parallel studies using two different approaches: Case study and Design Protocol study. The first study incorporating survey, studio reflection and focus groups was conducted to collect students' reflection on their project-based design experience and CAAD's use within the traditional context of the design studio. In parallel, a Protocol study explored visual thinking in the CAAD design process, and students' use of CAAD programs as a medium for conceptual design and problem solving.

The studio study was designed to better reflect the status of CAAD in the educational context at the studio because CAAD is not an *integral part* of the studio teaching. Furthermore, this study anticipated providing a "real-context" appraisal for CAAD related issues and to attempt to understand what is behind the tendency to use CAAD early in the conceptual phases of the design process. A questionnaire survey was designed and circulated and by directly observing studio activities, the study developed an understanding of the modern context within which students operate and interact, interviewing students during 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 CAAD on the traditional context of the architectural studio and the traditional studio context effect on CAAD's future integration.

The second protocol study was designed to explore CAAD as a design tool and to understand how students interact with it in the individual design process whilst also identifying the impact of CAAD on this process. This study also suggested a strategic approach to overcome the negative impact of CAAD use within the individual design process, and provide further insights for academics who may be asked for advice from an enthusiastic CAAD student.

However, there are drawbacks to both studies as they reflect one case study in the sense that it is a "*bounded system*" (Creswell, 1998 p.61). That is to say, both studies were carried out on final year students (Architecture and Architectural Technology) between 2006 and 2007 on individuals who reflect similar backgrounds of education, CAAD preconception and share the same setting of the institution and its pedagogy.

1.4 Thesis content

Chapter two provides a background of design theoretical assumptions, and studies of design methods and design processes.

Chapter three sets the scene for new design media and CAAD in particular. It outlines how CAAD evolution sets its inappropriateness for conceptual design and how continued advancements on many levels might change that in the near future. This chapter also aims to assess the potential usefulness of CAAD in the architectural design process as well as the educational learning process in the longer term.

Chapter four considers the doctrine of this research and the reasoning around the data collection methods used. A brief review of research methods in design research, and an extensive review of design activity research methods and the analytical approaches are provided.

Chapter five describes the process of designing the empirical studies and the development of the adopted instruments to demonstrate how the theoretical proposition in chapter two and three are linked through a mixed methods approach. This chapter also describes the coding schemes for the design process, segmentation, levels of abstraction, representations and design moves.

Chapter six presents the results of the questionnaire survey and the first stage of the case study data collection, to provide a comprehensive description of the study sample. This description is provided with respect to their CAAD learning experiences, design skills (architectural design, sketching and CAAD), design preferences and other drawing related preconceptions and views on the use of

CAAD in the early phase of the design process which also provides the knowledge base for the case study.

Chapter seven presents the findings of the second stage of the case study – the studio refection study. This study in a continuum for the survey but based on the collection of empirical evidence in investigating and assessing the impact of CAAD software programs on the conceptual phases of the architectural design studio. Data collection methods used in the study included: paper based questionnaire surveys, observation (studio's pinups review) and interviews.

Chapter eight presents the findings of the case study from the focus group discussion. The relationship between earlier findings and CAAD teaching methods was discussed whilst focussing on the recent trends in CAAD teaching as a knowledge base rather than a tool for presentation. This discussion complemented the descriptive analysis of final year students and CAAD learning experiences.

Chapter nine presents the design protocol analysis and results using two approaches: the first is the coding of the design process using a process oriented coding scheme (Gero and McNeill 1998), and the second approach is the linkography (Goldschmidt 1993), where further coding was applied to categorise the phenomena that were noticed during the interaction with CAAD, the individual's style and design process.

Chapter ten presents the discussion of the main studies results and any interesting triangulation between the themes and methods of the main studies and finally offers research conclusions and contribution to knowledge. This chapter also discusses limitations and opportunities for future research.

2 Design Theory

This chapter defines a theoretical design framework by describing both "*how designing is*" and "*how designing might be conducted*." (Cross 1993). The descriptive theoretical framework of design is presented in the first section, which provides an abstract body of knowledge about design theory, process, methods and studio context. Design methodology is explained in the second section.

2.1 Design

It is common to define design as problem solving that improves a particular state. For example, Herbert Simon (1992) looked at designing as a process of rational inference (Simon 1992; Dorst and Dijkhuis 1995), which implies that the problem is specific and known. However, knowing that each design problem is unique (Achten 2008; Dorst and Dijkhuis 1995; Schön's 1983) and that every designer tackles the same problem differently (Akin 2001) informs a different solution and reflects a certain level of expertise and knowledge (Eastman 2001; Akin 2001). This is much closer to Schön's (1983) proposition of "Reflection-in-Action". This is where problems are framed by designers, who take action (make moves) improving the (perceived) current situation (Dorst and Dijkhuis 1995 p.263). These two design paradigms conflict in "*ways of looking at the world*" (Dorst and Dijkhuis 1995 p.262). However, these views had a dominant influence on the descriptive formation of design methodology. This thesis is also concerned with the education required to become a designer. Schön provides a contextual description of design methodology in considering design as a "*reflective conversation with the material*" (Schön 1992).

2.1.1 Design situation

The design situation depends on what the designer can see and understand. *What if?* is a simple question set by Schön (1991p.) to define the design process as follows: "*to experiment is to act in order to see what the action leads to". What if?* is an essential question needed to carry out any kind of design problem solving task, within individual design processes, mediums and tools. Schön also considers design problems to be part of the design situation. However, each time a designer asks this question, s/he explores its possible answer differently to evaluate the result. It carries the nature of being iterative, similar to the design process itself. As a result, a designer can find many answers using different design methods and mediums. The basis for design exploration is through exploring different design situations. As a result, one can see the reason why this question is not only essential, but also original; no matter how many times a designer asks it.

Based on this notion, Dorst and Dijkhuis (1995 p.264) stated, *“Design is not just a process or a profession; it is experienced as a situation that a designer finds her/himself in”.* Designers try to understand an ill-defined problem by framing it to decide how to act in order to change the perceived situation; this understanding is based on the designer’s perception of the current state (Dorst and Dijkhuis 1995). This state is perceived in part through problem representation at the same moment of interaction (Reffat 2000). Other distinctive characteristics of the design activity are satisfaction, judgement, and representations.

2.1.2 Design problems

According to Simon’s view, the designer’s “*problem space*”, has to have enough information about the required task, and the functional requirement to enable the transitional move to the “*solution space*”, and information about what is required as part of the solution where the initial state of the design problem becomes part of the solver’s proposition (Newell and Simon 1972).

Based on Newell and Simon’s (1972), view of design as a rational activity essential to searching for a solution within a situated problem space, Akin (2001) identifies two aspects of problem *composition*: (1) the schema (*defined as an internal representation of the world*) used for decomposing, and (2) strategies used for recomposing. These aspects create invariants for the design field. In design behavioural studies, researchers have found that architects decompose their problems into sub-problems, develop variants and follow design steps. In a trial to decompose the main design problem into sub-problems, Akin and Hays (1999) proposed that there are two potential starting points that are constitutional in the structure of any design problem: (1) building type and (2) building component systems (enclosure, circulation, structure). In examining this normative proposition, one can deduce that designers start with the building type as the main problem in design and continue to study and relate the building type to the other component systems in order to solve these sub-problems. Also by solving the sub-problems, a solution can be found for the main problem that he/she started with (Lawson 2006). The building type is a critical starting point to decompose the design problem, as recognising this at the beginning of the decomposition process will determine which component systems are most critical and how choices can be made between these systems (Akin 2001).

The tools that help a designer act are also part of the design situation (Coyne, Park and Wiszniewski 2002 p.269): *"tools we use impinge on how we problematise issues".* As the designer, one needs these tools to change the perceived state and further interact with the resultant configuration. Thus, a design situation is influenced by the designer's way of framing the problem (strategy), level of expertise (knowledge), design task (building type) and the design medium. Therefore, a design activity has to compromise between the design task constraints and the medium constraints.

2.1.3 Design concepts

The process of perceiving the meaning of architectural design "concepts" is mainly grounded in architectural education within the context of the design studio-teaching model. The most asked question within an architectural educational context is "*Do you have a concept?"* and the answer would be either*: "yes I have,* or: *No, not yet*." Yet, as students, we are rarely asked what a "concept" means. However, it seems that a question like "What is a design concept?" has been, and still is, an essential question within architecture education as every conceptual reflection starts and ends with an idea, a solution or a decision. Where the meaning and feeling of "architectural design concepts" are learnt almost unintentionally, conceptual design experience is perceived and learned mainly by doing a studio project. This is much closer to Schön's (1987) notion of "*learning by doing*". Where theoretically, there was no induction to the architectural terminology before actually studying architecture, scholars have approached design concepts from two different perspectives. The first is the whole perspective (holistic concept), as design concepts in architecture are seen as the final artefact (a summary of the conceptual design taking or solving different aspects of the design task). The second is the partial perspective (atomistic concept), where design concepts are seen as transformations (Goel 1995), or novel decisions (Akin and Lin 1995) in which they unfold over time (a process of transformation and reformation of more than one concept). Using the term "concept" within the context of student learning could make borrowing from other projects or ideas based on other projects less frequent because of the originality aspect that the word “concept” implies.

2.2 Design Methodology

The paradoxical relation of design product and its methodology was and still is arguably the most debatable aspect of design studies. Is it the produced artefact or the process of the artefact production? Which one characterises design methodology?

Cross (1993) characterises design methodology as “*the study of principles, practices and procedures of design*.” From this quote, one notices the emphasis on design processes and activity over the resulting design. Moreover, based on the same notion, Kroes (2002 p.) states that a design methodology’s aim is “*to improve design processes; this means that it takes a normative stance towards its object of study*” and “*it is strongly process oriented*”. Furthermore, compared to *research* methodology, Kroes (2002) signifies the nature of *design* methodology as a “*rational reconstruction*” of real design processes, thus design methodology has schematised the design processes into various phases and models, for instance, analysis–synthesis–evaluation (Lawson 2006). These models are related to theories of design problem solving, design cognition and information processing.

Although the design process and the design product are directly interrelated and the existence of one justifies the existence of the other, design methodology has explicitly explored design theoretical aspects, which literally concerns the methods, strategies and techniques used in design problem solving. However, an understanding of the nature of the process of design (production) requires an insight into the nature of the design produced and vice versa (Kroes 2002). In architectural design, this could be inferred as one model for thinking (design problem solving). It is plausible to form models of rational inference through a design process in which a model can be developed, but it cannot be accepted as a *normative* stance for designing. Arguably, design products seem implausible to model or schematise as each product is individual.

Regarding the same line of thought (Cross 1993; Kroes 2002); Kroes (2002) stresses the need to know how to relate “*success*” and “*quality*” to design or the design process. He debates whether or not the success of a design process depends on the success of the process outcome. On the other hand, in describing the design activity as a process of reflection-in-action, Dorst and Dijkhuis (1995 p.272) have stated that "*successful moves*" are the design moves and frames that a designer kept and "stayed with" along the process to the end. They found that this categorisation would provide clear instances of "*the what, how and why of the design concept*."

However, design concepts and their relation to uncertainty as products of thought can arguably be traced through design externalisation. Design externalisation justifies the process that has been carried out in seeking a design solution. This can also be observed clearly within the linkography methodology (Goldschmidt 1993), of restructuring the design process into arguments and moves, taking and considering the design methods and its externalisation to justify the end result (design) by providing rational cues which are related to the design process (structure and content) (Goldschmidt and Weill 1998).

2.3 Role of Representations

The conceptual phase of design is mainly characterised by its lack of restrictions, which forms the basis for its iterative cycles, while the mind is free of traditional thoughts, open to new thoughts and able to acquire originality (McKim 1980). Thus the thought process involved would be described as explorative; consequently the result would be more creative. Further sketching is conceived as the sole medium for mind and thought process (Schön 1983; Goel 1995; Suwa and Tversky 1997; Cross 1999; Tversky 1999; Plimmer and Apperley 2002; Bilda and Demirkan 2003). Sketches in many domains are not presentations of reality; they are representation of reality (Tversky 1999). They differ from reality in important ways: they omit information, they add information, and they distort information.

Representations (internal and external) are part of the designer's ability to solve design problems depending on his/her ability to create a virtual world (Mitchell 1990), 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, this suggests different design worlds develop different types of observation of the real world, thus allowing different reasoning to be made (Mitchell 1990). It is also argued by Laseau (2001) that if someone is able to draw, then he is able to imagine in the first place (mental constructs), and imagining will feed back into the ability to draw.

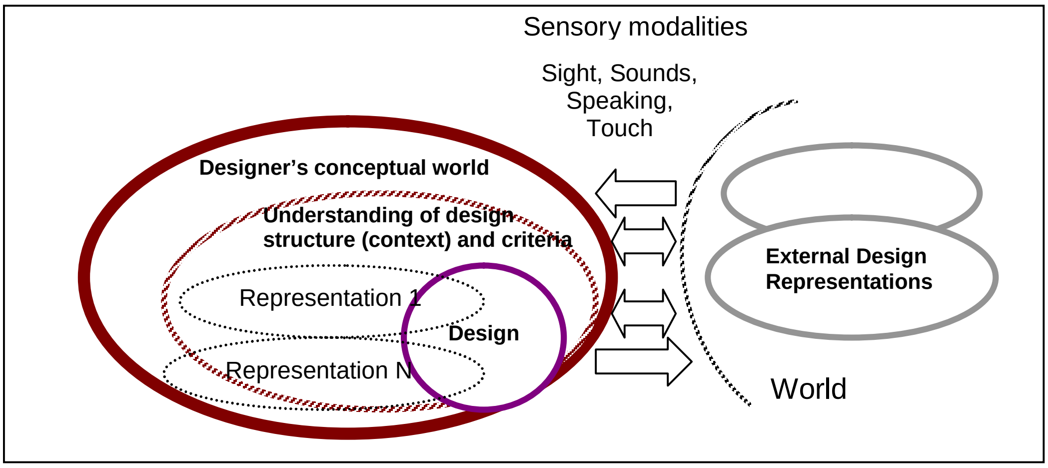


Figure 2-1 A designer's conception of a design and its context is built up over time (Eastman 2001).

In order to overcome the initial phase of problem solving constraints, technical - economical, complexity of brief requirements and incomplete information, external representations (ideas, drawings and models) are used extensively (Römer et al. 2001). Designers initially start to form their conceptual ideas in a visual-graphical process of relating thoughts and mental images. Therefore, the 'ideation' process evolves through a cycle of understanding, analysing and synthesising to implement an optimum solution for the design problem or question. This cyclic process is evident throughout the design process stages, in general, and during the conceptual design stage, in particular. This capacity is learned through studio contextual learning and reading external representations (Eastman 2001). Externalisation is not only used for short memory relief but also for developing ideas by interacting with the representation as a medium between imagination and external reflection (Figures 2-1 and 2-2).

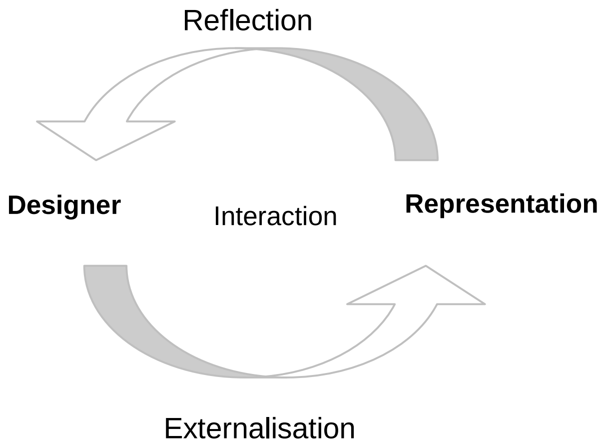


Figure 2-2 Externalisation and Reflection (Schön 1987).

External visual representations take place either intentionally or unintentionally, this is shown in Figure 2-3. Depending on its emergence ground, two visual representations can be identified: intentional and unintentional. The intentional emergent representations (objects or spaces) are easier to identify, as designers (students) deliberately and explicitly draw a particular shape (area, space or object) to create a visual reference for the design task requirements, or for reading information or as a response to a previously drawn shape or configuration. Moreover, these intentional emergent representations are situated within a set of visual attributes (shapes, angles and sizes) that were set by the designer (sometimes in accordance with the design brief) (Suwa and Tversky 1997). Additionally, the explicit shapes and their spatial relations could inform unintentional emergent shapes implicitly**:** it depends entirely on the viewer's ability in restructuring the resultant configuration *"… they are embedded as partial elements or implicit objects, and emerge to the viewer's eyes only when s/he discovers a new way of restructuring the whole configuration that includes those elements.*"(Suwa and Tversky 1997 p.388). Thus the unintentional emergence of shapes is based on the drawn configurations and how these configurations are interpreted by different people. An example is shown in Figure 2-3.

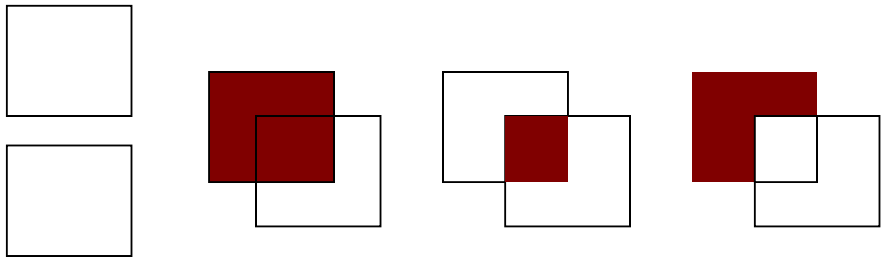


Figure 2-3 An example for sub shapes emerging (Mitchell 1990).

They have also suggested that spatial arrangements have the ability to express not only literal spatial relations, but also abstract-conceptual relations reflecting functional and economical factors. This analysis suggested three information categories: "*depicted elements, spatial relations and abstract relations*." In examining the design process, external representations reveal the emergence of the design: these external representations are either verbal (words) or visual (graphic).

This visual reconfiguration is considered as a phenomenon in other design studies, for example *sudden insights* (Restrepo and Chistiaans 2004), *discovery* (Purcell and Gero 1998) and *The Aha! Response, or the sudden mental insight* (Akin and Akin 1996). These studies emphasised the inductive role of the visual medium capabilities in containing (hosting) such emergence and the medium used in these studies was either 2D drawing or sketching.

2.3.1 Level of abstraction

Designing is characterised by being active and dynamic. The designer progresses through design in an iterative cyclic process(es) of analysis, synthesis, and evaluation (Lawson 2006 p.38). As the designer navigates through the problem domain, these cycles could happen at various levels of abstraction on which the designer is focused (problem-solving focus in relation to the situation), whether the designer is considering the problem as a whole or as sub-problems (Gero and McNeill 1998; Purcell et al., 1996). Moreover, Lawson claimed that designers have a specific kind of liking/inclination to 'concentrate' on their designs. Concentration is required for design problem solving but is also related to the size of the drawing under investigation, as designers tend to use small pieces of paper to make small drawings (Lawson 2004, 1994; Laseau 2001). Laseau (2001) associates this tendency with the need for the drawing to (fit) the humans' visual field. To elaborate on these views, the term "foveal vision" was brought to architectural design studies by Lawson for the first time: "*having the whole drawing in clear foveal vision would seem a very sensible pattern of behaviour under these circumstances*." Through this visionary type, designers intend to concentrate on specific parts of the emerging ideas to evaluate and refine them (Lawson 2004; Cross 1999).

The use of external representations (sketch, drawing, model, etc) combines internal, intellectual actions with external actions and their external result (physical). It is claimed that designers produce various types of external representation (virtual/physical) to overcome problem-solving information uncertainty (Christensen 2005; van der Lugt 2000 p.18-19). As such, at a certain point in time, each type produced (within the design process) a different degree of information uncertainty, in that it represented a certain level of specification of the problem under consideration. All types of conceptual representations are ambiguous in their general sense, in that they can be changed and transformed in a process of iterative refinement upon the designer vision. Stacy and Eckert (2003) emphasised *“the importance of combining sketches, words, gesture to disambiguate each other”.* Externalisation is thought of as an indication of the designers’ level of information uncertainty (Christensen 2005). This could be traced through the used language of a subject (for example: probably, may be...) and the parallel design activity of representation. According to Christensen (2005), different levels of information uncertainty could be assigned to different externalisation-types. However, it is not always possible to document the externalisation of ideas. Some ideas are documented explicitly by talking/ verbalising but without being documented (parallel action), which indicates that the subject is not that certain about the mentioned idea. Other ideas are documented by drawing them vaguely and others are documented by modelling or through modelling.

External representations are not only important to externalise designers’ thoughts and ideas but also as a learning process, by which design students develop their *imaging* capabilities (Eastman 2001). With repeated practice of reading external representations, reading becomes easier *allowing automatic interpretation* (Eastman 2001 p.173). In the same manner, design students become capable of using these representations to reason with mental processes. Familiarity was mentioned by Eastman (2001), as the first important step towards learning a new representation. Familiarity creates confidence in using the representation and then becomes common practice. Design students get familiar with a new representation, then using it becomes easier and “*The development of the lower level representational skills is a prerequisite for the high level reasoning and for the actions required of effective designers*.” (Eastman 2001 p.25).

2.4 Design Studio

The design “*studio is a unique setting which, while preparing students to practice the profession of architecture, is also a locus of discourse on, and of, the field of architecture*.” (Goldschmidt 2003 p. 5). Schön (1987) looked at the studio context as patterns of “doing and coaching” and a model for artistic teaching. In terms of the architectural design learning and teaching context, the contemporary studio still embraces its traditional methods of learning by doing, in which students are spontaneously experimenting with conceptual issues as well as making new (unexpected) discoveries (Tversky 2001; Do and Gross 2001; Goldschmidt 2003). This is called “knowing-in-action” (Schön 1987), and it is concerned not only with knowing but also with learning; reflecting on what the student has done since the start of the studio project to the point where the design option(s) are presented. Recalling this sequenced process of the continuous reflection on a design situation at a later stage is described as the “reflection-on-actions” (Schön 1987), which has no relation with the present actions (decisions) of the student. This might indicate that the process of reflection on action takes longer to be explicit. This sequenced process also includes sub-reflection processes, where the student’s knowing and learning would contribute to the design situation while doing it. Based on these kinds of reflection, the design activity occurs on two levels of interaction: on the macro level of self-project model communication and on the micro level of self-communication.

A designer’s words do not describe what is already there on the paper but are parallel to the process which he/she devises, 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 language, but can nevertheless be used to communicate (Tversky 2001).

As design language is described with respect to design theory and reflection, the modern practice at the studio provides another perspective of the used language. Habraken (2007 p.16-17) noted that some of the limits exist in the language used at the studio. Two aspects were observed:

- the language used by tutors reflects a personal vision of those tutors in describing the design world, yet there is no common language (disciplinary), therefore, a thing might be named differently by different people,

- Studio teaching and its conversational structure makes language more important compared to other (non-studio based) disciplines. There is no vocabulary about the making of form; instead the conversation conveys propositions of the design world, declaration of intents.

As a result of these two aspects, the critics' role has changed into a discussion about meaning or a putative observer's impressions, rather than seeking clarity about the student's work and the process, i.e. reflection on action.

2.4.1 Studio project process

According to Schön and Wiggins (1992), designing is an interaction of making and seeing, doing and discovering. This interaction works in certain ways and requires certain conditions that enable it to work. Each step of the design process is a microcosm of the whole process. It works as a cycle of the conceptual design iteration. At the same time, this microcosm is a response to one design question. Principally, it is part of the visual thinking process; it relates to the designer's snippet of drawing and description represents the whole design process. Each drawing or sketch is a snippet of the whole design process.

Studio work gives a model of work flow through representation and visual thinking. This is shown in Figure 2-4. This flow has two levels: the macro level and the micro level. On the level of macro interaction, the student's design activity is influenced by the studio tools and the project model. On the level of micro interaction, the student's design activity is influenced by the student's skills set and cognitive preferences.

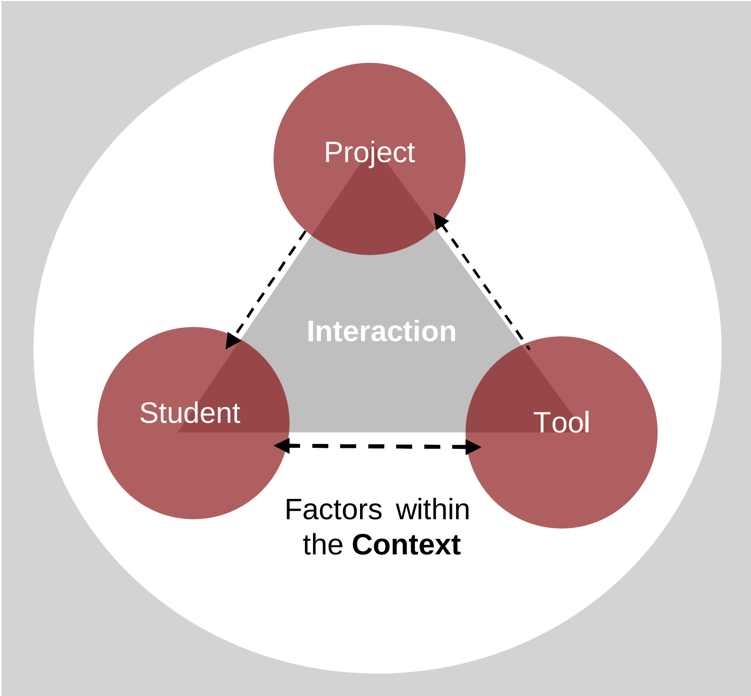


Figure 2-4 Designing as an interaction in the studio context.

For example, a typical studio design process consists of the two levels of interaction and goes through stages within an architectural project model that consist of: a) Design project understanding, b) collecting visual references, and c) Site analysis and first ideas. These stages are explained in more detail below.

2.4.1.a Design project understanding

This phase includes presenting a design brief for a client (whether an actual or an assumed one). Through this phase, drawings are used in ways to understand the given information and to remind themselves of what has been said (at this proposed briefing phase), to check what has been understood and to pass it on to their group. At this early phase, students use drawings cautiously though, as the use of "*over-prescriptive drawings is linked with lack of opportunity for creative input"* (Schenk 1991 p.170). In addition, this phase in practice would take place in intervals, but in academia, the reviewer (studio tutor, visiting lecturer) would take over the client's role and determine the client's criteria for the project. Students have to reach a sound understanding of the project requirements and its situated nature as the project information (brief and visual material) is passed from tutor to student.

2.4.1.b Collecting visual reference material

In this phase, students are looking for similar projects: this similarity is mainly based on the functional aspects of the design problem rather than any other aspect. It consists of collecting visual material from books, magazines and web-pages as precedents for the project. At this stage, drawings are used to reference certain parts /aspects of the evaluated precedent. It could be related to the level of abstraction that the student is working on. Thus it occurs at the beginning of the design project and at other points where the student is searching for a solution to a more specific problem. Drawings are used regularly by designers, whereas photography was reported as a preferred way to collect visual references to form a visual collection or a journal (Schenk 1991). Sketchbooks and project journals are both documented examples of this process and currently on-line databases and e-portfolios are used. Schenk reported that such material has cognitive implications for developing a designer's "*visual background knowledge"*. This phase's drawings range from drawing from observation *to tracing and copying from a reference source (p.170).* Schenk's (1991) study also reported another important finding: that designers, not only in their own use of drawing in the support of designerly activity, but also through the experience of observing and working with the drawings of others, play a part in developing their visual literacy, perception and visual memory. Thus, it is through working in an environment in which drawings and other representations are produced, as well as through their own drawing experiences, that designers develop the type of visual understanding and knowledge that can be brought into use as required.

2.4.1.c Analysis and first ideas

This consists of analysing the design problem and suggesting, externalising and exploring what they have been carrying and processing internally. *"To assemble their first thoughts they need a free ranging drawing style to be able to explore a greater number of ideas quickly, with economy of effort*" (Schenk 1991 p.170). This phase involves using a combination of rough visual notes and words to work out and test ideas, therefore, this stage witnesses the most rapid and frequent use of drawings.

Bearing in mind project model interaction, figure 2-4, the interaction between a student and a design tool is arguably controlled by the context of the project model and the stage pedagogy, through which the student (of critical appraisal in a design based context) is able to evaluate the usefulness of a tool through practice, that is active engagement in a variety of tasks. Such a situation (open interaction between the students and tools) provides two crucial conditions for evolution. The first is the interaction between the student and the tool within the context of a design project; and the second is the interaction under the condition of free engagement and new media acceptance. This results in developing a critical ability to assess student's own goals and monitor his or her actions (Meneely and Danko 2007 p.70).

At the heart of architectural design education, studio provides a vital context for traditional ways of reflection, learning by doing and visual thinking, which at the same time act as a medium for architectural learning and practice.

2.5 Summary

As far as this research is concerned, design media is argued to be the only factor in design theory that is changing and influencing architectural practice as well as the traditional context of the studio. The heart of this pedagogical change is in the studio and the learning methods, rather than replacing studio teaching. To illustrate some of the assumptions underlying design studies and to contextualise the impact of computers on the design process in the present practices of architectural education, CAAD oriented studies are reviewed. So far, design theory is the inspiring theory for CAAD-oriented research including the emergent theory of digital design. However, it is too soon to experiment into the practice of digital theory as the studio context is still missing the concepts, the terminology and the process. This chapter provided the necessary background for design theory and design studies in its methodological view. The next chapter reports on design studies in relation to new digital media and how digital design is emerging into the new design theory of digital architecture.

3 New Media and Architectural Design Education

This chapter sets the context for Computer Aided Architectural Design (CAAD) as a new media for design exploration. CAAD as part of the new media is reviewed in the first and second section. CAAD as a presentation method is reviewed in the third section, and a review of CAAD's role in architectural education is presented in the fourth section. The fifth section outlines an appraisal of the recent trends in integrating CAAD in architectural education.

Computers have radically changed the working methods of architectural design and production and CAAD software programs have affected many aspects of the methods used for communication, representation and production. However, in practice, the role played by CAAD has taken a different route than expected.

3.1 Media Evolution

In general, media is a well established term that relates to human ability to communicate with self and others. Since the rise of humanity, media has referred to some *material* or *technique* used for communication (Bennett 2005). No matter what type of media was used; whether a cave stone or a clay tablet, each was used for many years to enable the communication of ideas and messages. Although such communication was carried out through different types of strokes, pictures, or writings, they were all considered to be one system of communication. Eventually, advances in technology brought new methods of communication (i.e. photography, recorded sound, and telegraph). These methods revolutionized communication but each method still used one medium to send a message. This single medium was finally broken with the introduction of sound and motion. In this form, several different mediums were being used simultaneously, and a medium became media (Bennett 2005). The next big influence on what would become "new media" was the debut of the computer as a tool for communication (Breen 2004). To this end, Bennett (2005) describes "new media" as a combination of old media in ways that enable new *methods* of presentation. Media evolution took two different directions: one where humans started to use more than one medium to communicate and the other where technological developments fed our cognitive abilities with *support* and *choices* to communicate with self and others (Bennett 2005).

Following the same line of thought, computers have been seen as a revolutionary tool that would change design on different levels of practice, education and research. Breen (2004 p. 436) argued that the computer has become a platform for various media, many of which can be used in combination. Therefore, using “new media” in design entails two critical features of used methods: variation and combination.

3.1.1 The evolution of the CAAD as a new media

In describing computer systems in academia, Achten (1996) established some common ground in so-called computational issues (i.e. database structures, exchange formats, programming techniques, interface design, etc.) and difference in so-called architectural issues (cost calculations, facility management, production drawings, simulation, evaluation building analysis, design synthesis, form generation, etc). CAAD researchers and developers emphasise either the formal computer science point of view or the architectural design point of view (Kalay 2004) in developing or designing new or other appropriate CAAD systems. The variation of the philosophical perspectives of solving the problem of how to integrate architectural issues is what marks the distinction of CAAD generations. Moreover, this aspect of CAAD’s philosophical evolution is the main reason attributed to CAAD research complexity and diversity, since CAAD research is characterised by the increased frequency of new ideas emerging that have not been grounded in early work (Maver 1995; Reffat 2006; Kalay 2004).

The modern concept of CAAD was introduced by the scholars Sutherland and Coons (1963) by developing a graphical system, “Sketchpad”. This system formed the basic concept for the first generation of CAAD and it was designed to integrate the evolving design (from initially sketch drawing with a light pen then refining it with built-in shape assumptions into a perfect drawing) and analysis programs (numerical analyses). Through this process, the designer could interfere with an optimisation procedure (Coons 1963, cited in Kalay 2004). Also this could be seen as one of the integration concepts between computing analytical capabilities and architectural design. In contrast, the Architectural Machine Group (Negroponte and Groisser 1964, cited in Kalay 2004) at MIT took an artificial intelligence approach to developing architectural computing applications, in which the environment itself could originate actions on its own by sensing the needs for building inhabitants and incorporate changes without any interference from the designers. It is obvious that the main argument between the two approaches is the designer's role in a computerised environment.

The second generation emphasis was the graphical aspect of CAAD systems. This included new improvements in modelling and rendering capabilities, but in terms of building design, systems were less capable than before.

The third generation witnessed grouping of the significant characteristics of the previous two generations. Although the philosophical perspective might be the same as the first generation, the representational aspect is improved. However, it was improved successfully mainly because of technological advancements (computer graphics, minicomputers, and input devices). Also, based on the recent advancements in information technology that are taking place in both CAAD research and education, Reffat (2006) proposed a fourth generation. This proposed approach would envisage architectural designing to be carried out collaboratively and synchronously within smart and real-time 3D virtual environments to include the current successful computational experiments, i.e. situated digital design (Gero 2002; Reffat 2000), smart 3D virtual design environments, designing with agents (Gero 2002; Reffat 2003; Saunders 2001). This review of CAAD evolution shows that CAAD's development was not sequential, but underpinned by different perspectives and developed through hardware and software advances. However, the resulting systems were classified in academia under four main categories: Social systems, Professional systems, Educational systems and Innovative systems.

3.1.2 Computer systems in academia

Before reviewing the incorporation of CAAD in the teaching curriculum and the traditional studio, a definition of computer systems in architectural education is sought. Based on the different rationales behind teaching information technology in architectural education (Plomp 1996, cited in Achten 1996), a computer systems classification was first described by the Design Methods Group (Achten, Dijkstra, Oxman and Bax) of the Department of Architecture at Eindhoven University of Technology. Their work distinguished four computer systems in education: social systems, professional systems, educational systems and innovative systems (Achten 1996) as shown in Figure 3-1.

Social systems are computer tools, which all students should be able to use within any higher education curriculum. *Professional systems* are computerised tools which are used in architectural practice (that is AutoCAD, 3ds Max). Usually these systems are off-the-shelf software, that is, software developed by standard software companies (that is Autodesk, Microsoft). *Educational systems* are modified professional systems to convey specific pedagogical purposes and are developed within or for a specific architectural institution and sometimes result from research. *Innovative systems* are computer systems that reach beyond current state of the art professional systems (that is automated plan recognition, virtual reality design systems) and are always the consequence of research work, hence they are so-called "home-made" software.

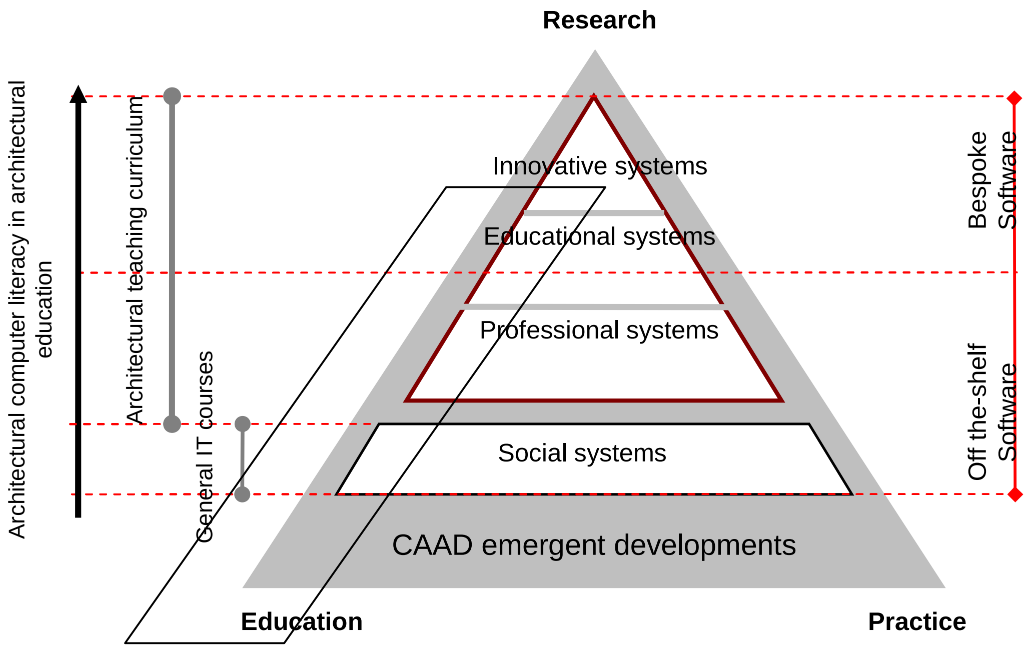


Figure 3-1 CAAD systems in architectural teaching curriculum and computer literacy.

Most architectural schools consider the integration of computer literacy and CAAD as one concept (Mark, Martens and Oxman 2003), which involves the teaching of two types of computer systems: social and professional. However, this can be extended to include the other two systems (Achten 1996) but this depends on the institution's pedagogical approach and the proposed role for CAAD in design. In recent years, Garcia et al (2007) challenged professional (commercial) systems by proposing an educational system that has the same aspects of (Auto)CAD commercial software and an easy learning curve for engineering design students compared to AutoCAD. However, the students preferred to learn and use AutoCAD although it is more difficult to learn for two reasons: CAAD's advanced *technical* aspects and its role in their future career (Garcia et al 2007 p.779). This also reflects the common perspective of why these systems are important in design schools and design teaching.

3.2 New Media Characteristics

"New media" is a term that has been used in many studies (Bennett 2005; Watkins and Russo 2005; Oxman 2006), and is mainly generated through digital methods of making computers (Bennett 2005), computation (Khan 2001; Oxman 2006, 2008), and information technology (Oxman 2006), whether using traditional methods or emergent new methods of communication.

To approach design "new media" studies and research we need a unique set of sub-definitions. "New media" studies are challenged by their technologically evolving nature which becomes one of their defining characteristics (Watkins and Russo 2005). This makes assigning an exact definition to "new media" problematic and uncertain. As Watkins and Russo (2005 p.145) state: "*While it is difficult to pin new media down to an exact definition, new media may be described as any digital media production that is interactive and digitally distributed."* One might argue that, this problematic situation gives some indication as to what could be considered as new media in our design study context. From Watkins and Russo's description, there is a binding distinction between what is considered as new media from that which preceded it, mainly because it is produced and distributed by digital means. This implies how new media is perceived, used and transmitted. As a result, what makes any media be seen and experienced as new media is the observed differences in the nature of its *interactivity*. Interactivity is argued to be the most important aspect for new media and future development (Watkins and Russo 2005 p.145).

In the same line of thought, media and interactivity have been explored in design studies, based on the nature of the designer's interaction with the media. According to Oxman (2006 p. 243-4), media has four levels of interactivity as illustrated in Figure 3-2. A designer interacts with:

(1) *A paper-based representation:* at this level (1) of interaction, the designer is interacting directly with a representation of the designed object visually through a drawing or physical model.

(2) A *digital representation construct*: at this level (2) of interaction, the designer is interacting with CAAD by means of a visual sketch or a digital drawing, either in 2D or 3D format model.

(3) *A digital representation generated by a mechanism:* at this level (3) of interaction, the designer is interacting with CAAD through a set of rules and (spatial) relations to form a mechanism to generate a *digital structure;* this is arguably mediated by information.

(4) *A digital environment that* ***generates*** *a digital representation:* at this level (4) of interaction, the designer is interacting with *"the operative part of a generative design mechanism."* Where the designer "*can interact with the computational mechanism that generates the digital representation."* this is arguably mediated by more advanced information and knowledge (multi-knowledge designer).

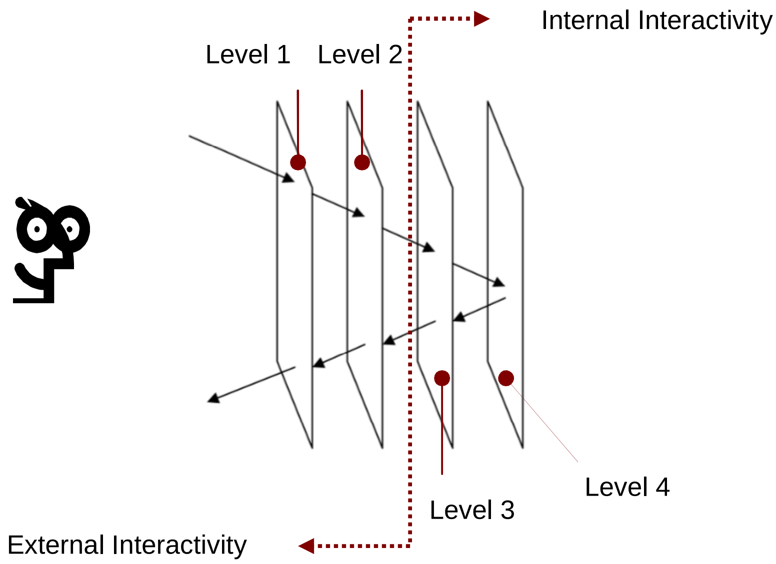


Figure 3-2 Interactivity levels with design media (according to Oxman 2006).

In the first two levels (1,2 are illustrated in Figure 3-2), the designer interacts with the shape s/he draws on paper and the emergent shapes. This is further classified as *external interaction* (Oxman 2006 p. 243). Oxman (2008) asserts that Schön's conversational characteristics have one aspect that is the "*backtalk*" of the visual image. This can be true with the first level of paper–based interaction, but on the second level of interactivity- digital based- this can be argued as the interaction goes beyond the 2D image of a representation into 3D objects, explained in Figure 3-3.

The other two levels (level 3 and 4) are classified as internal interactions meaning that these levels of interactions go deeper than the surface level of the visual aspect of a representation, to manipulate the computational medium in different ways, requiring a different form of action. Hence, the last two levels clearly reflect the new requirement for knowledge requisition of the "*toolmaker"* (Oxman 2006 p.231) designer, and consequently the digital-skill level will vary. Arguably, the last two levels of interactivity are the most challenging in relation to the knowledge (Oxman 2008) that is required and are part of the future direction rather than changes that might occur in the next ten years. There would be a different outcome if computation (programming) became a common knowledge or skill, or if computers became simpler with respect to such (operative) computational mechanism(s). These two are hypothetically "*re-introducing a different medium of conceptualization, replacing paper-based media*"(Oxman 2008).

In this thesis, it is argued that the second level of interactivity has more than one layer of interaction, on the two modes of visual thinking: 2D and 3D. This can be categorised further into layers of passive and active interaction. Passive interaction agrees with Oxman's (2006) proposition of the visual talk back and active interaction is when the represented objects are manipulated and modified on CAAD. Each layer is defined by the mechanism used and the potential representation that CAAD can provide its users, as shown in Figure 3-3. As we move towards the other uses and levels of digital interactivity, new knowledge is needed to bridge the gap between the known and unknown. Thus it is argued that the knowledge required will be different from now on and will affect the designer's role as well as new requirements for practice and education. However, architectural practices are ahead of those in design education (Lawson 1997 and Cross 2001), which is still based on Schön's framework of reflection to support the thinking process in the studio as well as the self (student), and the role that representations play in the design process, knowledge and methods.

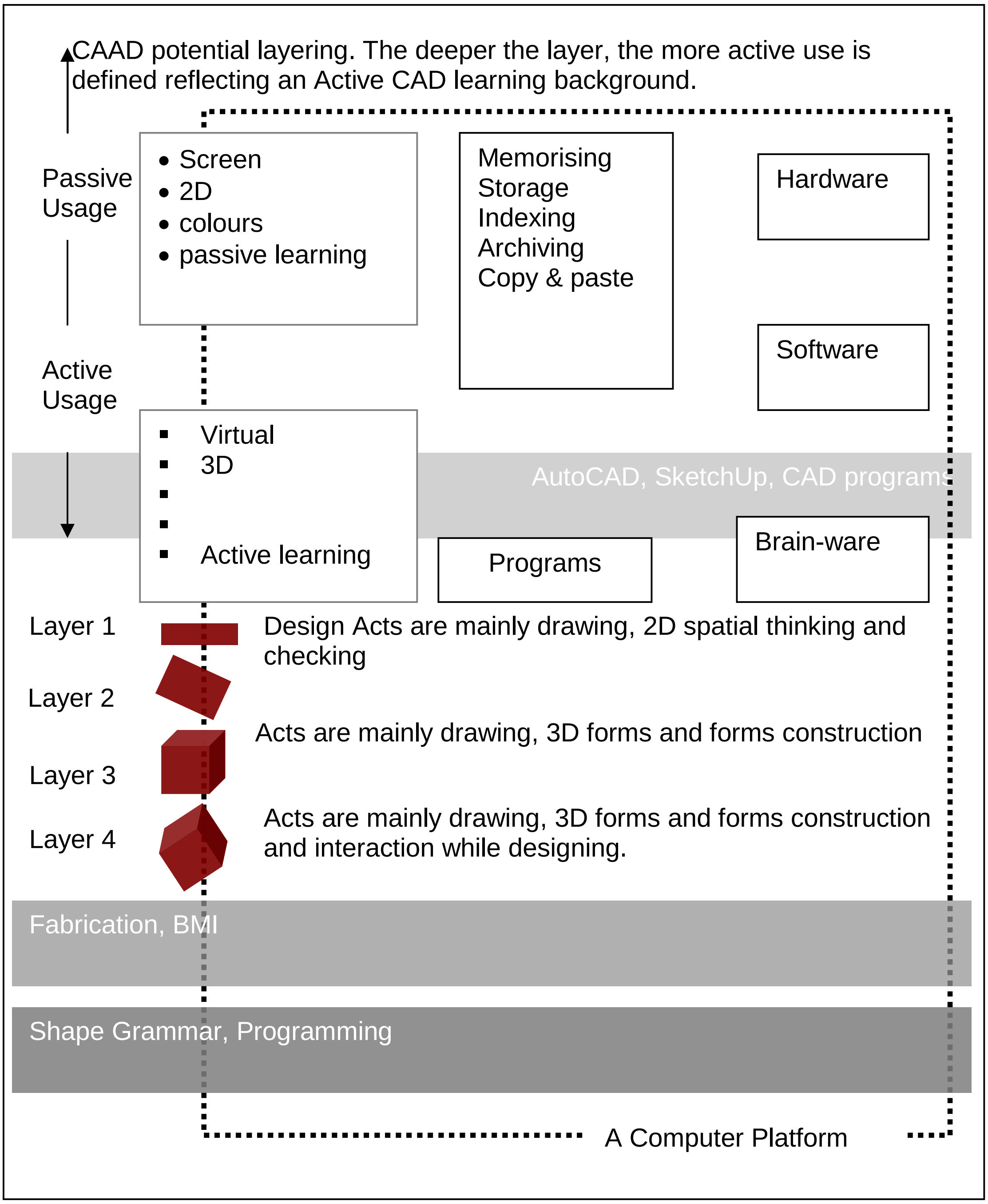


Figure 3-3 Interactivity on the first two levels is classified into layers of 2D and 3D representations.

To conclude, these two sections have reviewed the continuous change in defining CAAD in terms of the possible levels of interactivity. The current levels of interactivity have been examined and will be discussed further in relation to architectural design education in chapters 7,8, and 9. These levels further determine whether a CAAD system is used for presentation or representation (designing). With respect to digital design discourse the differences are huge and rooted deep in education and practice. To reduce these differences, a common terminology must be developed and transferred between the two.

3.2.1 Future design skills

"New media" implies new roles for both the designer (Oxman 2006) and the student, although retaining a "central" role in the design process. "*The designer today interacts with, controls and moderates generative and performative processes and mechanisms. Information has become a new material for the designer*" (Oxman 2006 p. 242). This new role will take the form of "toolmaker", maintaining, customizing, and operating the new media (multi)-systems (Oxman 2006, 2008). Furthermore, this role sets further requirements for a new specialized generation of designers with knowledge, practice, and skills.

With respect to the term "information", one question is raised: What was the context for the information of Oxman's claim: "*information has become a new material for the designer?*" Is it the basic information (knowledge and experiences) that design is generated from? If this is the case, then why is it denoted as new? Is it because such information is mediated by digital technology as an added value? This is open for debate taking Breen's (2004) view of media as being the means for conveying "*all kinds*" of information.

Alternatively, does it reflect the evolving skills (knowledge) of the future designer? Information has always been the medium for designers. What makes it new, though? Arguably, Khan's (2001) supposition of "computation as a medium", provides an early understanding of how computation can be thought of as a medium. While he was elaborating on Binkley's (1997) distinction of the two main media types: digital and analog, he suggests that information within digital media has moved from being *transcribed* from one physical material to another (analog) to being *converted* from a physical material to a numerical entity (digital). This conversion allows users to manipulate the numerical file (physical object/ physical material attributes) through computation to be converted back to the image on the screen. However, digital media changes the design experience in terms of **materiality** constraints. As Binkley (1997 p.110) claims, *"the two functions of storing and displaying information are relatively independent*." This separation between storage and display allows users to manipulate the numerical file through computation (Khan 2001) via the third level and the fourth level.

3.3 CAAD Representations

In this section, visual thinking is revisited with respect to CAAD system representations and design theoretical framework. These are discussed on the first and second levels of media interaction.

In the same context as Schön's theoretical framework in which he states '*to experiment is to act in order to see what the action leads to'*, would it be possible to view CAAD systems as the latest medium for design conversation? When we look at a CAAD program we should not look at what it does in a technical sense, rather we should look at what it does in a visual sense. Designers are visually oriented and are taught to think graphically (McKim 1980; Laseau 1980; Do 1998). Visual representations vary in order to contain the process of design and to communicate both process and outcome (Mitton 1999). With respect to students, the defined complexity of representing their mental constructs, which are blurry and uncertain, in a legible way that reflects the logic of the design methodology implies two operative modes (in the light of Ambach 2006); conceptual representation and concrete. Both be obtained through CAAD representations of conceptual emergence and structure.

In the context of this research, CAAD's representations are the practical methods of encoding data into graphical images to explain a concept via the CAAD medium. Different visual techniques make visual thinking possible and improvable: each concentrates on ways to free the mind from traditional patterns of thought. Interest in CAAD representations and effects on the early phases of design have increased as students and designers have reached a different level of awareness in terms of computerised visual appearance and working methods (digital skills). The question of whether CAAD is solely a presentation medium or whether CAAD could be a medium for mixed levels of interactivity that facilitate sudden insights should be addressed. Therefore, new research should look at whether CAAD changes the way designers reason or changes what designers are representing by analysing their design methodologies.

Throughout the development of architectural design media, many transitions have occurred, where architects and designers took many years to understand and exploit the potential of a medium in conception. CAAD has passed through this in the final stages of the architectural design process (Dokonal and Knight 2006), in which designers have developed certain strategies to overcome CAAD's potential restrictions. As a conceptual design tool, CAAD seems to be passing through a similar process of exploiting and understanding. However, CAAD restrictions have always been defined in relation to sketching and were evaluated on this basis, thus its claimed restrictions were based on preconceptions or perceptions of sketching as the predominant thinking tool and CAAD must dismiss the former. In the early days of CAAD development, programmers' attention was focused on creating a program to automate the drawing board, not the designing brain, therefore considerable research was undertaken in exploring new trends (in programming) to suit conceptual design by facilitating a sketchy behaviour within a digital environment.

Researchers have explored the traditional design methods in the invention of new conceptual design tools to aid designers in creating architectural designs (Do and Gross 2001). However, similar studies established that differences between sketching and other (digital) tools are the most valued such as Coyne, Park and Wiszniewski's (2002) study. This study demonstrated that by proposing a new digital tool "device" that enables the compilation of hand drawing with digital media, i.e. using digital board with digital pen, may enhance the value of design practice but it also brings differences which are valuable in understanding the new method.

Table 3-1 The differences between CAAD representation and sketching (based on the following studies: Coyne, Park and Wiszniewski2002; Binkley 1997; Breen2004; Khan 2001).

CAAD representation	**Traditional representation**
Dynamic (viewing) reflects on more levels while viewing	Static reflects on the considered level of abstraction
You can "see" extra visual effects (automated effects: colour, line weight, texture)	You "see" what you draw
Active and Passive changes	Active in making a change in a representation
Drawings Reuse (whether elements or objects) and pre-drawing reuse	Reuse by tracing over previously drawn –Redrawing
Virtuality	Reality
No materiality constraints (unlimited)	Materiality constrains (limited)
Storage and display independent	One storage and display – dependency

The differences between the two representations continued to be significant and suggest that looking at the differences between the two is the most interesting theme, some of these differences are listed in Table 3-1. Thus the potential of CAAD as a representation and its visual impact has to be examined per se in more depth and not on a comparable basis. More time and effort needs to be spent in exploring CAAD as a new medium for design.

3.3.1 Visual Thinking and CAAD

One of the basic assumptions in this review is that it is possible to find qualities or characteristics of CAAD or any other design tool that make it more or less suitable for conceptual design. This is observed mostly in students when they use a certain tool which they deem appropriate. Thus describing CAAD as a tool and as a representation medium that can provide the means for visual thinking is discussed.

Currently, a variety of media, tools and representations is used within the studio context, as discussed in section 2.4. However, studio is described as traditional for two reasons: its pedagogy (not embracing digital media as an active part of the curriculum) and the produced representations. In the traditional context of the studio, students are expected to develop their own design methods and strategies. However, sometimes tutor knowledge and (traditional) methods intervene between the process of learning and the suggested strategies.

In a related study (Jonson 2005) on conceptual tools, design students concluded that negative views of CAAD conception depends mainly on the surface understanding of the conceptual tools. Quoting Jonson: *"Arguably, then, the view that CAD is inappropriate for conceptualising seems to be based on a preconception of conceptual tools as surface, rather than deep structures*." (Jonson 2005 p.622).

Design studies have focused on sketching and its impact on designing whereas the role of other media, e.g. imagery, discussion, reflection and CAAD, have not been examined in as much detail. Jonson (2005) argued that currently the primacy of sketching, as a primary conceptual tool needs more evidence. This study (Jonson 2005) utilised a comparative case study as the main methodology, with five design students and five other design practitioners. They were asked to design various design briefs (10 design problems) in their related field. The data was gathered through their daily practices by jotting down the most frequent conceptual tool they had used. As a result, Jonson concluded that sketching is not the dominant conceptual tool; instead, he found that verbalisation is the most used tool or the combination of verbalisation and other conceptual tools (Jonson 2005 p.621). The combination of different conceptual tools such as modelling, sketching, words and CAAD (computer) also reflect that design is a dialogue or a conversation between verbal and non-verbal methods. Moreover, Jonson concluded that CAAD emerged as a conceptual tool across different design domains. CAAD is not just a technical drawing tool but also a conceptual tool capable of developing new ways of conceiving and perceiving design (Jonson 2005).

Whilst recognising that sketching is restricted, different to what is viewed and done in the CAAD medium (Lawson and Loke 1997; Verstijnen et al. 1998; Purcell and Gero 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. A review of the literature suggests that hand sketching and CAAD visual techniques can be used in conjunction, rather than being treated as separate mediums (Bermudez and King 2000). All of these techniques can contribute to a better evaluation of the envisioned design product. Different media 'talkback' in different ways (Schön 1989; Breen et al 2003; Lawson 2004; Mitchell 1990). 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 professional systems of CAAD software programs (i.e. SketchUp, Photoshop, and AutoCAD). Breen (2004) reports that this introduction has led to the development of more personal and varied working methods (Achten 2003; Achten and Reymen 2005) 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 program to include *personal methods* of integration and association between digital, physical, 3D formats, and any other media that assist the designer in concept (re)structuring (such as photography) and (re)interpretation.

Hence, the combination and integration of tools and representations could bridge some of the cognitive differences between the students and between the qualities and characteristics of the two media. As a result, CAAD is aiding some of the students, and even when the approach used enhances the combination of the two, there are situations where the traditional method is preferred over a digital method of making (c.f. Zuo, Leonard and MaloneBeach 2010). However, one participant (1/51) deviated from the prevalent trend of this study (Zuo, Leonard and MaloneBeach 2010) findings, to work mostly on paper media. This was due mainly to the student's level of skill in hand drawing in both sketching (thinking) and rendering (presenting), and in conceptualising and form generation, which appear to be two different skills but seemingly related. On the contrary, based on experiential evidence, Lawson (1999) found that the quality of conceptual design was enhanced by CAAD in the case of one architectural design student where he had sound technical and functional problem solving capabilities whilst having poor drawing skills which hampered his confidence in exploring complicated forms or shapes. Therefore, CAAD could be appropriate for some (novice) designers to use in conceptual design.

Based on drawing (2D or 3D) studies, Schenk (2007) acknowledges digital skills not only in controlling the technical aspects of design but also in enabling those who have weak drawing skills to resolve difficulties and present their ideas better. This also emphasises that the need to draw has a lasting impact on visual thinking and problem solving whether using sketching (Goldschmidt 2008) or using digital means (Schenk 2005, 2007).

3.3.2 CAAD inappropriateness

The quality of CAAD being unsuitable for concept design is based on some of the software visual features as well as the comparison with other medium features (sketching) that are valid for conceptual design. Some studies have suggested that uncertainty is one of the key factors that allow the vision of the new possibilities of representation, and thus allow re-interpretations or unintentional visual emergence (Goel 1995; Suwa, Purcell and Gero 1998; Suwa and Tversky 1997). With respect to this, discussions on the use of CAAD emphasized that CAAD has no such ability to provide designers with new insights. On the one hand, this view is correct but to a certain degree it seems controlled by the designer himself; by his ability to reconfigure what he is conceiving from that level of roughness and the design situation. Stacey and Eckert (2003) have explored ambiguity in rough sketches in terms of communication between knitwear designers, and claimed that in terms of a CAAD wire-frame model, this shows almost exactly that the perceptual interpretation is too narrow. However, Stacey and Eckert (2003) provided two possibilities to overcome such defects in CAAD's exact drawing and models by: 1- the possibility of faking the exact appearance through sketchy or fuzzy lines (Stacey and Eckert 2003), and 2- the designer's ability to remain aware of "*the actual range of possibilities, so the apparent precision presents no problem*." (Stacey and Eckert 2003 p.172).

Consequently, this view is correct but could also be argued with the advent of new CAAD tools enabling digital sketching with a friendly interface, e.g. Autodesk SketchBook Pro 2009. It may also vary depending on the individual characteristics of a designer as compared to another designer. The technology advent shifts the discussion and perspective to the designer's (the one who interacts) ability and opens the way to other possibilities.

Design cognition studies claim that CAAD is inappropriate for conceptual design or restrain conceptual design. These claims were based on interacting with either sketching only or switching between paper and CAAD; these studies employed design protocols analysis. For example, Tang's (2001) theoretical implication for CAAD systems was the speed of the designers' intention shifts. The results indicated that designers, both experts and novice, shift their design intentions rapidly while sketching. The speed varied from 7.7 seconds for the expert and 20.3 seconds for the novice. Based on this result, Tang claimed that using a (current) CAAD system, would "block" the development of thought, as "*the time this expert took to shift his intention was not enough for him to pull down a menu, select the function, and input parameters.*" (Tang 2001 p. 98). Consequently, this would affect the time spent on designing. Tang's claim was based on the speed of designers' intention shifts during sketch design to theoretically suggest that CAAD would "*block*" the shifts of intention if the designer was using CAAD. This study did not examine CAAD actively in the same way as it recorded sketching as it is of interest to study design activity (interaction) within CAAD systems.

Based on cognitive studies and methods, comparative studies have framed digital design studies. For example in Bilda and Demirkan (2003), the experiment was set up to observe two groups of designers (3 designers in each group). Every group had to go through three sessions of sequential media switch. The first group started with sketching, and the second group started with CAAD and every group used the opposite interchangeably for the next two sessions. On a general level, cognitive actions were found to be significantly different between the two groups in each session for three main reasons: (1) while designing in CAAD the participant worked with a 3D environment that affected their conception by making them evaluate more attributes than the ones intended while thinking of an alternative. Thus, the CAAD design process became time consuming. (2) On the level of the individual skills, the findings referred to the participants' habitual design methods as one constraint that affected their use of the CAAD system in its full computational capacity, which made them novice CAAD users (although they had previously taken CAAD courses and a training program to gain the same level of proficiency before starting data collection). (3) All cognitive activities were relatively higher in the traditional media than digital media, which "*might limit their cognitive interaction with the digital media*" (Bilda and Demirkan 2003 p.47). However, modifying actions were higher in the CAAD media compared to sketching. Moreover, CAAD software is inflexible to support the habitual physical actions of sketching and tracing. Furthermore, they did not interpret this as a hindrance to thinking or seeing in digital media but as a variety of design situations: "*but as designers varying mode of thinking and reasoning in different media*." And also "*Designers' sketching activity seemed to have different dynamics in different representational media in terms of design thinking and making."* (Bilda and Demirkan 2003 p.48). This study provided an empirical context for Tang's claim. However both studies agreed that designing with CAAD systems would need more time either because of the thought speed (Tang 2001) or the handling of more attributes during conception (Bilda and Demirkan 2003).

In comparison to other CAAD oriented studies within the studio context (in section 3.4.1), one of the emphasised impacts of CAAD on the design process of the macro level of students interaction is efficiency and productivity (Dokonal and Knight 2006 Al-Qawasmi 2005). This suggests that what is actually happening (experienced) during a design activity on the micro level of interaction is different from what is experienced on the micro level of design activity interaction in the cognitive studies, which is mainly considered “block of thought” (Tang 2001) and time consuming (Bilda 2001).

3.4 CAAD Role in Architectural Education

While students are becoming more computer and digitally literate, they are imparting knowledge and skill (Bermudez and King 2000) in 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 contribute. Currently, describing a contemporary design studio would seem rather traditional, but doing so by engaging with various media would open new perspectives for design methodology.

In terms of design computerisation, Andia (2002) identified that professional practice and architectural education are developing different arguments in this field. Architectural practices are effectively improving the traditional ways of architectural design by digital technologies integration. On the other hand, in education, computers have been used in architectural schools to challenge the view of architectural practice: architectural studio becomes the setting to examine the computers contributory role in architectural design. In academia, many support this “modernizing” view (Schenk 2005), therefore an increasing number of architectural schools are becoming an exploration setting for various design media interactions and integration (Ataman and Lonnman 1996; Bermudez and King 2000; Ataman 2000; Al-Qawasmi 2004, 2005; Knight et.al. 2005 Dokonal and Knight 2006). As we shall see, CAAD software programs continue to affect architectural thinking in a number of ways.

3.4.1 Studies from the educational context

In recent years, challenges have been extended to include the need to develop new (digital) skills (Achten 2003; Al-Qawasmi 2004, 2005), to rethink architectural design (higher) education (Al-Qawasmi 2004, 2005), in the light of new developments in CAAD software programs and consider how this might bring change to the studio context.

Dokonal and Knight (2006) held a workshop to study two groups of participants (18 students in each). One group worked with digital media and the other group with traditional media. They looked at the process of how each group developed the given design project by documenting the process visuals (SketchUp models, and sketches and physical models). A difference in skills was the main factor that affected the evolution of their work. Furthermore, the students with strong digital media skills were faster than other students in both groups but the traditionally skilled students were able to reach a similar level to that of the digital group but took longer. This study did highlight one point: during students work review, an observation was made by the reviewers (tutors) that the digital models looked complete. This impression was sometimes based on the appearance of the model only without the appraisal of the content, i.e. concept (p.814). It is suggested that using digital media alone in design exploration has new advantages with some disadvantages.

In conclusion, the findings of these studies suggested that there are media-based differences among students in the design process. Younger students are using digital modelling quite naturally in the process as they tend to be more adventurous. This allowed the students to understand their own design better. This was also in agreement with Al-Qawasmi's (2005) findings in substituting traditional methods with other methods, and developing their design ability in a short time.

Most of these studies (e.g. Hanna and Barber 2001; Dokonal and Knight 2006; Lu 2008) were carried out with students in their early stages of education. This suggests that an early-stage student is a better subject for studying attitudes and design media effect on thinking as they have no previous experience of CAAD, and no preconceptions or design habits that could bias the results. However, no study has focused on the acquired skills for the long term teaching of CAAD in schools of architecture and whether the teaching methods used were appropriate or effective. It is, however, problematic to trace the development of design students' expertise (Dorst and Reymen 2004), whereby a longitudinal study is required to survey different cohorts within the same institution pedagogy. In any case, the more manageable way is to focus on final year students not only to identify their preconceptions but their reasons for having them, hence evaluating the teaching methods. This thesis, therefore argues that the reason why CAAD is perceived as a presentational tool is rooted in the teaching methods and the teaching context.

The development of novice designers to experts is not that evident in design education but assumed to be gradual. In recent times, researchers like Reymen and Dorst (2004) investigated this development process in an educational setting and how design research would record this change in design education and integrate it further into practice. It is important to establish a theoretical basis for understanding design students' educational transformation and to know 'how to stimulate design expertise development' (Reymen and Dorst 2004). Knowing this has been argued to be important for efficient learning. Taking this into CAAD skill development, it has to occur in parallel to design methods to reflect the specificity of a design exercise at a certain stage in relation to the design methods taught and the design tools provided. There have been few studies that looked at the individual's experience of CAAD applications in the context of the studio. Especially when the skill varies immensely (Fellows, Clarkson and Elysee 2009), and how such skill can be measured in relation to other skills (design and sketching) in the same context, especially when CAAD is learned in earlier years of education and out of studio context. An integration between the two learning curves should be sought rather than leaping between different levels and assuming that it is a gradual development. Thus, every stage will prepare the student for the next level, rather than starting from unknown levels of expertise.

3.4.2 Effect of the workspace on students

Mazijoglous, Scrivener and Clark (1996) presented the term *design workspace* to refer to the tools and media that are available to students (designers) in a shared workspace (studio), such as pen and paper or CAAD software programs, and the students' interpersonal communication channels (reflection). Presumably, students can move freely between both spaces. In the studio, one can observe both interpersonal interactions between participants 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, Leonard and MaloneBeach 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).

3.4.3 Effect of CAAD on Studio

Al-Qawasmi's (2005, 2004) study of the e-studio categorised students' practices in terms of using CAAD solely in the design studio, into enhanced practices and displaced practices. The methods used were questionnaire survey, interviews with students and jury instructors after each e-studio. The enhanced practices were (1) integrative mode of working where the students' acts and decisions are saved in a digital construct or representation, (2) interactive mode of working where design manipulation is immediate (3) reflective through instant feedback, there is no time gap between the two, the immediate response to change is seen as a consequence rather than acting on the result through reflection, and (4) immersion felt in two modes, one of which was during projecting their models and navigating through their 3D models and the other was felt with the many choices of form generation. These effects reflect a 3D dominant mode of thinking and interactivity with design exploration. These have displaced other traditional based practices in design representations such as physical modelling, conventional representations, and difficulties in documenting previous thought processes. Also this study suggested that gaining digital skill needs time and practice. Students experienced difficulties when they started designing as they needed more time to gain confidence and develop the skills required to switch their habitual methods between the two media.

3.5 CAAD Systems Teaching and Learning

Schmitt (1999) emphasised that "*research and education in architecture should place more emphasis on introducing the computer as a medium with various capabilities in order to improve the chances of architecture graduates in the long term*." Currently, architectural design methods are semi-digitised by merging the computer with a conventional formation of design, mainly executed by the use of drawing as a medium. Moreover, this is mainly because there is no educational design link between CAAD systems and new methods of designing (digital design methods). Learning by doing (project-based exercise) includes repetitive work such as drawing (representation), but it has a conceptual expression at the same time. i.e. the act of drawing as a technique is the repetitive aspect of learning-by-doing method, but the changing aspect of this exercise is the design project, and as each project is different in its constraints and criteria, this would consequently drive a different solution.

Another aspect of this learning method is building experiences to reflect on its action while acting as a response to critical thinking. This reflection is part of the learning experience and thinking process. In general, this method of learning aims to provide the student with a certain level of design ability to become confident enough to practice design after graduation (Eastman 2001; Cross 1999).

After setting the discourse for CAAD design process within design models and theories, in the next sections the integration of CAAD into studio teaching and design methodology is addressed. The following sections will consider and question what it means to integrate CAAD, with respect to student's attitude versus studio tutor's attitude, creativity hindrance versus enhancement alongside other factors.

3.5.1 CAAD curriculum as part of ITC

Penttila (2002, 2003) has explored the relationship between architectural education and digital media in architectural schools across Europe at university level and claimed that, "*IT-teaching environment in the architectural schools and the reception of new media information has been very positive."* (Penttila 2003 p.601). There is a significant correlation between computer literacy and its utilization (Van Dijk, 2005) and the success of integrating computer systems with architectural education depends on the way we integrate and relate computers with architectural design and theory. In many cases, the proposed curriculum has not been successful in integrating computer literacy with design inquiry, this separation was realized by the students and brought together by their practices and needs. Bille (2002) explains that using the computer for communication, writing and other purposes already familiar to the student has facilitated the integration of computers into 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 has indirectly brought new skills and tradition to the studio context. Often, the proposed curriculum was not successful in integrating computer literacy with design inquiry (as it was integrated in IT literacy). Loy (1999) reports that inexperienced CAAD users "*need to discover digital design as a primary designing tool as well as for communication.*" This process can be achieved successfully by introducing computing and CAAD methodology in a friendly, understanding, and motivating atmosphere.

With respect to the taught software programs, Loy (1999) argues it is necessary to inform non CAAD users of CAAD applications to enable them to assess which software is the most suitable for their needs. Moreover, Schenk (2005) warned about the dominance of one particular software in academia. In recent years, Meneely and Danko (2007) have emphasised such awareness as an important factor in building students critical ability to evaluate digital tools' usefulness and need. Garcia et al (2007), suggest that through teaching the principles of CAAD in another language, this would eliminate the concentration on one design program. Moreover, CAAD situated learning in problem solving would help students learn CAAD but at the same time "*they learn the basis of CAD automatically while using the time in practice with a theoretical content*." This was also proposed by Ozkar (2007), by emphasising learning design through computation principles that are similar to design composition and re-composition. One way is to teach CAAD with respect to the principles of architectural design instead of software teaching.

The following section attempts to answer the question "to what extent can the studio environment (exploration, tutor personality, and perceptions of CAAD) affect the creativity of students using CAAD?

3.5.2 The role of studio tutor

Initially, integrating CAAD into the architectural studio curriculum faced strong resistance from studio professors, thinking that skills in CAAD 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* (Andia 2002 p.8) as they drew from the developments in practice. By the early nineties, CAAD literacy courses were accepted and introduced to the curriculum of architectural education (Andia 2002) and developed through many years of research. Moreover, as CAAD became more powerful and widespread, CAAD proficiency became a prerequisite to employment after graduation hence a crucial skill for graduates.

Applying CAAD in conceptual design, in the context of the studio education, had a significant impact on students' creative use of CAAD and design creativity enhancement. According to Edwards (2001) the impact of technology on an individual's creativity within the context of teaching and tutoring was highlighted. He stated that the conditions most required for creativity are being open minded to new ideas and having the willingness to explore the "*unknown.*" Whereas, "individual encouragement" is the most important aspect of the student-tutor relationship in developing creativity in the student (Edwards 2001). Individual encouragement leads to exploration, and exploration that is open to new ideas will lead to new insights alongside students' willingness to explore the "unknown" (Edwards 2001). On the other hand, lessons could be learned from other artistic disciplines, as the use of digital technology in art is widely accepted as a practice that enhances creativity (Wood 2003).

The effect of habitual methods in education and practice on studio tutors should be taken into account. Pektas and Erkip's (2006) survey of interior design students (62 senior students) focused on the students' perception towards computers in general and their relationship to CAAD use in design, and the tutor's attitude towards computers. With respect to the tutors' attitude, the study found that the student's perception is influenced by the tutor's attitude; if the tutor has a positive attitude toward using CAAD then the student has a positive attitude and vice versa. However, this would not change their preferences or attitude toward using CAAD in design. This study also reports that students were enthusiastic in using CAAD systems, however, when they were asked about "*producing design concepts"* students' opinion was not positive compared to other design aspects. Moreover, traditional methods of teaching CAAD emphasised the presentational features of CAAD systems (Basa and Şenyapili 2005) and lacked any knowledge about CAAD's capabilities of design simulation and analysis.

On the other hand, CAAD enthusiastic teachers are exploring CAAD practices in the studio and learning from that experience to provide a valuable opportunity to critically evaluate current design discourse to reconsider current understanding of design studio and digital practices. Al-Qawasmi's (2005) e-studio teaching experience is seen essential to other schools of architecture who still embrace traditional methods of teaching and using CAAD. It is seen as a mixed strategy that blends teaching and reflection on what is being taught simultaneously. Another aspect of this approach brought CAAD to the studio in its extremist sense of being the only media for design. Another example for active teaching was Lu (2008 p.89):"*The semester was not only a learning process in …. design for the students, but also a learning process of effective teaching for me. The observations and interviews in the studios provided considerable information to change my teaching to fit student needs."* Thus, the learning situation of designing with CAAD has affected the practices as well as the perspectives of the students, tutors and jury instructors.

3.5.3 Perspectives for CAAD Integration

Many educational programs were proposed and developed in the field of architecture and engineering disciplines which aim to integrate digital tools in the design curriculum (Oxman 2008) as opposed to the customary approach of integrating CAAD into the IT curriculum. However, at present the teaching in many, if not most, of architectural design schools falls behind in this respect. The project model of design in many of the architectural studios is still firmly based on visual thinking and reasoning with paper media (Oxman 2008; Zuo, Leonard and MaloneBeach 2010; Basa and Şenyapili 2005).

Recent trends in integrating CAAD teaching into a studio project model consisted of using digital design precedents from the industry to emphasis CAAD impact on design methods and form generation (Achten 2003; Achten and Reymen 2005), and by emphasising contemporary issues of the built environment through employing both CAAD and manual methods of making and evaluation, for example, focusing on sustainability issues using environmental analysis tools. The following studies show some of these trends.

The majority of the tools that designers presently use result in representations that emphasise the product of the design process (design) rather than the process of designing. The knowledge of design methods behind the product remain concealed and may be lost (Tidafi and Iordanova 2006), and hence cannot be learnt or shared. Advances in technology, including CAAD systems, are changing the processes as well as the methods through the emergent representation in industry of greater awareness of the new tools and their processes. This should be reflected in educational teaching methods and processes, thus new strategies should be proposed or experimented with. Many CAAD teaching researchers, e.g. Tidafi and Iordanova (2006), Achten and Reymen (2005), emphasised that architectural precedents aid the introduction of digital media to a studio context through design methods application (Achten and Reymen 2005; Achten 2003) or experimentation (Tidafi and Iordanova 2006). It was observed that both approaches were successful in identifying the digital design and as a result, this influenced the students' methods (their individual design strategies) as well as their awareness of the design processes and its knowledge.

A recent study by Zuo, Leonard and MaloneBeach (2010) confirmed that using a CAAD (Performance-Based Design) approach as part of the knowledge requisite for the (interior) architectural design curriculum is essential. Moreover, it has a significant role in emphasising contemporary issues of the built environment, such as sustainability and building performance, which supports students' awareness of the specified issues. Zuo, Leonard and MaloneBeach's (2010) approach modified the traditional design process, and affected not only the scientific (building energy use) aspects of the built environment that were raised but the spatial and aesthetic decisions also. Fifty-five (51 completed the survey) second year students (interior design) were enrolled on a four-semester course to focus on studio and CAAD studies interchangeably along the four semesters. All the students worked on the same project and were asked to use a combination of CAAD and manual methods of design exploration. The new approach (Zuo, Leonard and MaloneBeach 2010) of the project model shifted the studio instructor role into a more critical role. It was observed that the new role encouraged, besides working on a one to one basis with the students on design issues, a technical supportive role to solve CAAD operational questions, and monitoring the project construction and progress in two formats: digital and physical. As instructors they became closer to being project directors than supervisors. This was categorised as an active teaching mode.

The participants described SketchUp as easy and less accurate compared to other CAAD systems (e.g. VIZ) for 3D (free form) exploration. Also when compared to physical modelling it was described as "less forgiving", and faster to transfer a physical model into a digital model. Digital accuracy helped the participants to find problems during the transformation process and notice other problems that were identified by their instructors in the physical format. However, fewer participants claimed that the physical modelling was important as it engaged the senses to understand the spatial aspects (volumes and dimensions). As a result, the group who worked in the studio had made more modifications than the CAAD group, mainly because of the visual quality of CAAD models and images which restrained the state of the unfinished, therefore, there was more to complete. A sense of enjoyment was reported when the students experimented through design simulation (e.g. walk through, and real time interaction) to experience the form, the spaces, light and context.

The results of the study showed a positive impact on exploring design in a combination of physical and digital modelling. Digital modelling was ranked significantly higher than physical modelling in aspects such as lighting experimentation and design modification. However, physical modelling was ranked higher for seeing their design site in context compared to CAAD various techniques. The study results suggested three main points:

- all (digital, physical modelling and CAAD simulation) media used were effective to assist design thinking.
- adapting similar approaches would initiate a transformational change in the student's preconception of a CAAD presentation tool to a thinking supportive tool.
- teaching CAAD techniques in conjunction with design theory and methods to reflect on both; design thinking and final presentation.

In the traditional approach of the same studio there were no design explorative studies carried out using CAAD. However, employing the approach has changed CAAD's role into that of an active assistant with "*two-fold, .. visual reasoning, and building performance simulation,*" (Zuo, Leonard and MaloneBeach's 2010 p. 275). This also augmented "*the diversity and depth of design thinking.*" by adding another thinking cycle(s) of design evaluation at an early phase of design. As a result, the project model was successful in transforming CAAD usage from being a presentational system that presents what was developed manually (paper/ physical modelling), to one that actively supported that development.

Continuous advancement in CAAD has helped to change the design process and the traditional studio context, but at a slower pace than in other design fields. Through a critical and practical appraisal of media types, designers became aware of the capabilities and limitations of each media in relation to their own practice. Media awareness by *intermixing digital and traditional representations brought* "*smarter practice"* (Mueller 2006; Zuo, Leonard and MaloneBeach 2010 p. 272).

3.6 Summary

CAAD has been discussed in this chapter in relation to two kinds of study: cognitive/experimental studies as a media compared to sketching as another media for thinking, and studies that are carried out within the studio context (project model). The discussion reflects on the surface approach to CAAD learning, which is determined by the prevalent trend of using CAAD passively on the first level of interactivity (external). That implies a presentation tool which may witness minor insights for the sake of conceptual design. The main variables identified in the review were (1) the characteristics of today's student should be considered in more depth in relation to skill sets and design method preferences, (2) the architectural practice and the emergence of digital architecture as a new media and knowledge base, and (3) the changing nature of digital technology towards more friendly software programs and applications.

Thus in the context of design curriculum, there is a need to redirect CAAD's integration towards new ways of design exploration (Zuo, Leonard and MaloneBeach 2010). These practices have never been explored systematically within studio teaching. However, this is changing and the shift in attitude towards CAAD has just started to be explored by CAAD enthusiastic tutors and instructors (e.g. Zuo, Leonard and MaloneBeach 2010; Lu 2008).

How CAAD would influence a student's design process is not yet understood. However, it is recognised that the majority of architectural design students, as part of the wider student population, are described as a motivated sample who use CAAD on their own, and where this is the case, it is important to understand how the interaction is taking place. Alongside this, another point which should be taken into consideration is student's preferences. Therefore, studying a hypothetical interaction in a similar situation is important even if it is argued by some studies as inappropriate. Most studies in CAAD are descriptive in the sense that students have positive attitudes towards the use of computers in design on a general level. However, in relation to CAAD practical methods, investigation should be carried out on many levels from the perspective of the student as well as the tutor.

To conclude, designing is an interactive activity that takes place in the studio context. Interaction between students, workspace tools and project model has to be investigated on two levels: the macro level and the micro level. With respect to the educational setting, the macro level of interaction is more constrained compared to the micro level which is more individual and spontaneous. The latter level reflects the student's design methodology, experience and tools' preferences. However, most design studies have investigated design activity in relation to tools and media on either levels of design activity.

In the next chapter, the methodological means are discussed with respect to design studies and CAAD oriented studies. The methods that are considered aim to pragmatically investigate CAAD impact on students on two levels of design visual interaction: the macro level and the micro level.

4 Research Methodology

This chapter outlines the context for design research, design research methods, and CAAD-oriented research. Two strategies of inquiry are specifically considered: case study and design protocol study. Design research is outlined in the first section, design research methods in the second section, and “design process” research approaches are reviewed in the third and final sections.

4.1 Design Research

Design research methodologies correspond to the *various* points of view that design as a domain has established, whether the studied aspect(s) design process or the design artefact. The various points of view reflect either design practice or design education. In that respect, Reymen (2001) separates the *“world of designing”* fields of attention in to three separate fields: *design research*, *design practice* and *design education*. Moreover, she claims that interaction between the three fields is important in producing design knowledge that links each field of the designing world. Through this interaction, (Figure 4.1) design knowledge is generated and applied through design practice and “*design practice applies and generates design knowledge, design education transfers this knowledge, and design research produces this knowledge (together with design practice).”* (Reymen 2001).

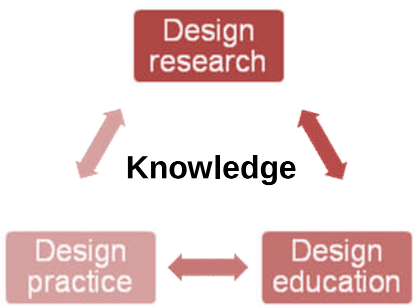


Figure 4-1 Interactions between the three fields of attention in the design world (adapted from Reymen 2001).

However, reviewing CAAD status in both design practice and design education (Chapter 2) indicated that the interaction of the two knowledge bases is still problematic. One example in this thesis has been identified in chapter three: the extensive use and status of CAAD in design (professional) *practice* vs. design *education*. Achieving a better interaction would arguably change the status of the applicability of CAAD from one domain to the other. As knowledge and praxis are evolving separately (Andia 2002), design practice and design education are the context in which design research is taking place to generate and contribute to design knowledge. Thus design research should direct the emergent knowledge back to both contexts as shown in Figure 4-2. As a result, design education and design practice would be informed through design research's emergent knowledge. Building on each other would help bridge the identified gap, by strategic means of research interaction.

Thus the investigative (physical) *setting* is a significant factor in the overall research approach to design processes and mediums which affect the research methods used. For example, the studio setting provides a reliable indication of the relation between studio practice, education and design medium.

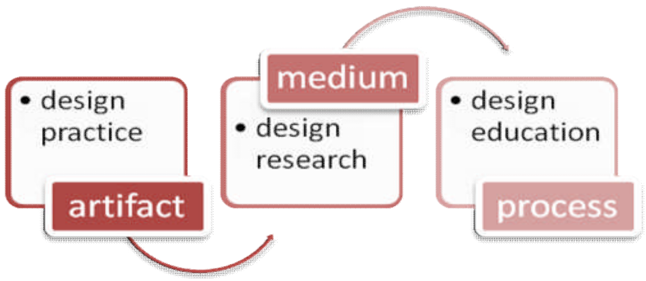


Figure 4-2 The transferred knowledge between the designing world fields of attention with perspectives on Artefact, Process and Medium.

What makes design research rich in terms of method and opportunity is the nature and characteristics of the "design process." Variation in design research comes from its studies on design process, design medium (including CAAD research), design artefacts and design thinking, whether the investigated setting is practice or education. CAAD research, for example, *"has extended and developed design research..."* (Tweed 2001 p.618), which was informed by design process and CAAD development studies. Thus, looking at design activity through CAAD, in turn would inform not only CAAD research, but also design research. Thus, the research methodology of this thesis would support the "process" point of view of design research as an investigative methodology, in that it is interlinked with design theories, mediums and thinking.

Equally important to design research is knowledge transfer, by which design knowledge is best educed in a domain-independent way (Reymen 2001; Reymen et al 2006). The theoretical and practical similarities that design disciplines have pertain to design methodology concepts and common terminology, for example, process, situation, frame and methods. As such, building on other design disciplines knowledge can be useful in two ways: (1) the anticipated increase in comparative / relative research and results with other disciplines' design processes and terminology, and (2) the potential complement of the weaknesses of other disciplines by knowledge transfer, which otherwise cannot be completed or augmented. Thus, this thesis has cited design domain independent studies that pertain to the following design concepts: problem solving, reflection, situation, conceptual design and abstract drawings.

Considering CAAD research in architectural design, a research weakness lies in the discontinuity of present and past efforts in CAAD-oriented design research, in that the present efforts of research do not build on what has gone before (Maver 1995; Reffat 2006; Kalay 2004). Therefore, many emerging new ideas pertaining to early work, were almost forgotten (Maver 1995; Reffat 2006). The other aspect of this discontinuity is seen in the distinctiveness of architectural design and such previously made efforts are seen as diverted intellectual effort. For example, Maver (1995 p.22) considers "*importing concepts and procedures from other disciplines*" as "*obsession*" that "*has diverted intellectual effort from the central task of identifying and understanding what lies at the heart of architectural design itself*." This "*obsession*" clearly had targeted CAAD research efforts at the level of inventing and developing new CAAD systems, rather than utilizing current CAAD (professional) systems in architectural education that other design disciplines have advanced in by exploration and acceptance. In responding to Maver's point, Koutamanis (2004) claimed that CAAD research should be established through "*a core research discipline based on the substance and true nature of architectural designing*." That could, to a degree, be true but research must also address other facets of CAAD that are accepted and dealt with accordingly in other design disciplines. For instance, the status of CAD research in mechanical design, product design and engineering design. The difference between CAAD status in architectural design and other design disciplines pertains mostly to designers' attitude (mindset) towards CAAD in the first place; acceptance versus rejection. However, Schmidt (2004) agrees, "*design research brought much needed knowledge into the nature of design*" (Schmidt (2004) cited in Reffat 2006 p. 659).

4.2 Design Research Data and Methods

From a design "process" point of view, the phase of the design process is a key factor in design research methodology, which determines data quality, quantity and variation. The conceptual phase is considered (in design thinking studies) as the richest phase of the design process life cycle, where data on design thinking fluently emerges through *reflection.*

Conceptual design is an *under-researched area* (Hadjiyanni 2008 p.55) and, recently, scholars have called for more efforts to understand conceptual design. Conceptual design is the earliest phase of design forming, and this phase is the starting point for design conception where ideas are expressed and developed gradually. In this thesis, studying this phase of the design process is approached by applying (concurrent) protocol studies.

The research reported in this thesis is situated and focused on the conceptual phase of designing for the following methodological reasons:

- the phase is informal and complex, but relatively short consisting of large amounts of information that is versatile and generated within a relatively short time,
- for its significance and impact on the ensuing phases of the design process, and
- this phase is arguably not currently aided by CAAD software programs.

Methods which have been used in design research have focused on understanding design and design thinking. Each researcher (Cross 1993; Cross and Cross 1995) has approached the design research from a unique set of variables, assumptions and goals. This will be summarised through mapping the types of research questions and the methods that have been used. Design research might involve interviews with designers (e.g. Cross and Cross 1995; Lawson 1994 and Schenk 1991), observations and case studies (e.g. Achten 2003; Achten and Reymen 2005; Candy and Edmonds 1996, Robertson and Radcliffe 2009), reflection and theorizing (e.g. Schön 1987; Simon 1981; Dorst 1995; 2008), and protocol studies (e.g. Cross, Christiaans and Dorst 1996; Bilda 2006). In addition, questionnaire surveys are used to collect information pre/post experimentation, collecting attitudes and preconceptions (Do 1998; Al-Qawasmi 2004; Hanna and Barber 2001). Most of these methods are used for researching design ability and to obtain designers' reflection on the processes and intermediary representations they are using (Cross 1999). "*CAAD-oriented design research*" (Tweed 2001) might involve similar methods such as interviews with the designers, observational studies of designers, statistical surveys of architectural education and practises and thinking about design. Tweed (2001) also suggests that CAAD theory formation should rely on combined sources (mixed methods) rather than using one source of knowledge.

This thesis' research methodology aims to observe the conversational aspect of a design "process" (iteration cycles, ideation). Design process (practice) acts as a rich source for reflection, which pertains to the reflective aspect of design (referring to Schön's 1987) theory of conversation with the material. At the same time, reflection has a methodological aspect and can be used as a research method in design as well as other fields, whether the investigated setting is practice or education. Reflection can occur along with designing (concurrently) or after reaching a satisfied result (retrospectively). Design process studies inspired the empirical element of this research to emphasise two paradigms of design research methodology: the constructive and the reflective-practice.

Thus the current research is interested in two main research strategies: case study and protocol study. Both strategies are appropriate to achieve the research objectives as both document the design process. The following sections present the review of structured reflection methods (Reymen 2001) that resemble Schön's model of *reflection-on-action,* and think-aloud method which could bear a resemblance to Schön's model of *reflection-in-action*.

4.3 A Review of Case Study and Methods

Case study research is wide spread in social sciences and education (Scott and Morrison 2006; Yin 2003). According to Robson (2002 p.178) a case study is: *"a strategy for doing research which involves an empirical investigation of a particular phenomenon within its real-life context using multiple sources of evidence*". Another mentioned feature was its flexibility as an approach to combine quantitative methods and qualitative methods in one study. Moreover, Scott and Morrison (2006 p.17-18) state that the main focus of a case study in educational research is to give the case actors a 'voice' in such a way that the researcher's role may sound passive to the benefit of the case actors.

According to Yin (2003) and Kohlbacher (2006) the essence of case study data collection is captured by three main features:

- dealing "*with a full variety of evidence-documents, artefacts, interviews, and observations*"; (Yin 2003, pp. 8, 97-105)
- creating a database;
- "*maintaining a chain of evidence*." (Kohlbacher 2006 p.6).

Case study approach may utilise a number of methods and serve different research purposes in changing contexts, e.g. conceptual design and design process. Moreover, case study analysis consists of three main strategies, either based on theoretical propositions, emerging explanations or case descriptive analysis (Kohlbacher 2006; Yin 2003). A deeper level of analysis is specified by Yin (2003 p.109) as: "*examining, categorizing, tabulating, testing, or otherwise recombining both quantitative and qualitative evidence to address the initial propositions of a study*". This suggests that case study analysis consists of qualitative and quantitative methods. However, case study findings generalisation is one of the limitations of using a case study. Scott and Morrison (2006) state that case study researchers do not have to make any claims about generalisation, instead they draw conclusions that are transferable to similar settings or situations or share the same problem or gap.

4.3.1 Structured Reflection

Based on the reflective paradigm (Schön 1987) in section 2.2, Reymen (2001) proposed a model for reflection to offer designers a framework (then a prototype) for structured reflection. Later this model was used to propose a software prototype to accommodate reflection on practice to help designers improve their design processes (Reymen 2001; Reymen and Hammer 2002). Structured reflection is defined as "*support for systematic reflection regularly during a design process*." In this framework, reflection was structured on systematic durations. The duration unit was defined as one design session that would last for half a day. Reymen (2001) suggests that to trace the changes from the beginning to the end of a design process (structured) reflection should take place at two distinct points in time, namely at the beginning of a design session and at the end of the design session. Furthermore, she explains the aim of each reflection as follows; reflection at the beginning of a design session "*should concentrate on changes that occurred between two design sessions"*; while reflection at the end of a design session "*should concentrate on changes in the design task, executed during the design session*." (Reymen 2001).

Subsequently, this methodology was improved and used successfully by Achten and Reymen (2005) to address a number of specific design process-based questions on specific aspects of a CAAD teaching course that employed open-ended questions to collect students' reflections in a trial to assess the student's learning and the proposed course. Therefore, this methodology when translated into practice may employ various methods or mixed methods that design and design education research might involve (i.e. interviews, observations and case studies).

4.4 A Review of Protocol Study and Methods

Researchers have used *Thinking Aloud Methods* in the architectural design process to theorize 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 (novice, expert) should think aloud while performing a specific design task within a medium. These could be paper drawings (Schön and Wiggins 1992), CAAD (Bilda and Demirkan 2003), mental imagery (Bilda 2006), or physical modelling. Moreover, van Someren, Barnard and Sandberg (1994 p.33) 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 (thinking) 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).

The second workshop, '*Research in Design Thinking II- Analysing Design Activity*', in 1994, held at The Delft University of Technology, revealed a range of approaches to analysing design activity and was an important milestone for this research methodology. However, it gave another dimension to design studies by which protocol analysis has been validated as a research technique for design (Cross Christiaans and Dorst 1996 p.13). The protocol variables were set to one design task in two modes of design activity: a single designer and a team of three designers. The analysis of designing and collaboration in that workshop revealed approximately nineteen analytical perspectives. This variation mainly came from the participating researchers' "*goals and approaches to the analysis of design activities"* (Cross, Christiaans and Dorst 1996, p.5).

The theoretical framework of collecting *concurrent design protocol* is discussed next - the discussion covers the critical criteria for protocol collection procedure, sampling-frame and method characteristics.

4.4.1 Design Protocol data collection

As suggested by Ericsson (2002) and Ericsson and Simon (1993), the possibility of eliciting valid verbal data from subjects while designing (task performing), depends on the way the researcher instructs them to accomplish the experimental task. Subjects are encouraged to verbalise without any interference in a sequence of thoughts. As verbal reports' quality and validity of information sequence increased by reporting thoughts concurrently with "*minimum time intervals"* (Ericsson 2002) between thought occurrence and its verbal report, this criterion is seen as difficult or unattainable. Another limitation is the impact of the think-aloud method while performing the design task, with studies like Young (2005) referring to reactivity to thinking-aloud which affects the subject performance. Reactivity relates to the participant's ability to think and talk at the same time, and the how talking aloud would affect the participant's way of carrying out the task, which is otherwise done in silence. However, in design protocols the visual interaction is supporting the continuity of the process and such limitations for some students (confident, motivated) can be overcome. Methodologically this implies a wider data collection to enable the evaluation and selection of the most appropriate protocols. However, these limitations may be improved through two methodological facets (van Someren, Barnard and Sandberg, 1994 p.34):

- the sampling-frame, as the participating subjects should comply with these two criteria (a) "*the degree of expertise"* and (b) "*verbalisation skills."*
- *the problem given,* the experiment task "*should be difficult enough*," but can be solved in *"an automated way."*

All these key studies agree that concurrent protocols take longer than other methods. One way to contextualise this is the impact of verbalisation on the cognitive process "*that people are able to slow down the normal process to synchronize it with verbalisation." (*van Someren, Barnard and Sandberg 1994 p.33). This is also supported by Ericsson and Simon (1993) who emphasised one condition of the previously mentioned point of the data collection procedure: "*if studies meet the criteria for procedure, giving concurrent protocols does not change the end products of thoughts; except by increasing the solution time due to the verbalisation*." This was also verified in "design" protocol studies by Tang (2001), and Gero, and Tang's (2001) comparative studies of concurrent and retrospective protocol while using sketching as part of the problem-solving task. They added that subject's practical involvement in sketching is another reason for the longer protocol. This discussion suggests that a subject may take relatively longer (compared to other used methods) to finish the task when a concurrent protocol is employed. In any case an evaluation step is valuable before heading to analyse a protocol with a poor quality.

4.4.2 Think aloud data is context bound

Many previous protocol studies including Gero and McNeill (1998) lack one aspect of data analysis, which is visual/verbal complementarity. The design protocol is a medium for two types of data, *verbal data* and *visual data*. This was termed by Akin and Lin (1995) as the *dual mode model.* The status of the dual mode of data is complementary: visual thinking echoes graphical data and verbal thinking echoes what is considered conceptual. As both studies, (Akin and Lin 1995; Gero and McNeill 1998), analysed the same design protocol, the latter study was concerned with the verbal data as the primary data source for analysis, while the former looked for evidence of novel decisions in the visual data as well as in the verbal data. Thus both data were considered as primary sources. Moreover, Mazijoglous, Scrivener and Clark (1996) also looked at sketching activity by "*emphasising the rationale behind drawing development*", in which a drawing's development was only considered (traced) where there seemed to be a strong synergy between the designer's two modes of thinking; external representation and verbalisation, as these actions alternate frequently. One activity echoes the other one, and one cannot be sure if the subject is engaged in purely conceptual (verbal) or visual (graphical) tasks (Akin and Lin 1995). Akin and Moustapha (2004) also employed concurrent protocol studies to collect pen and paper design protocols and CAD-based protocols. This variation was based on extending representational media rather than comparing it. However, this study focus was on "*better understanding of the specific cognitive processes contributing to massing*" in architectural design. It is related to design strategy research, where visual data has to be considered. Data segmentation is of interest in Akin and Moustapha's (2004) study, as segmentation was based on verbal, visual data and their combination. As such, protocol segmentation "*captures comprehensively and simultaneously the designer's graphical representation and her corresponding verbalisation. These verbal expressions encapsulate the motivation and rationale that are not evident in graphical representations therefore, clarifying possible ambiguities that are often present in the latter*." (Akin and Moustapha 2004 p. 32).

In concurrent protocols, verbalisation is one tangible part of thought externalisation. Verbalisation is not the whole of thought externalisation, as non-verbal pause(s) is considered as another part of the thought process (Lloyd, Lawson and Scott 1996). Reviewing the literature, non-verbal thoughts can be found mainly in two instances: a transition of attention (Lloyd, Lawson and Scott 1996) and a reflection of information uncertainty in designing (Christensen, 2005). Therefore, raw protocol data consists of verbal utterances, visual configurations and pauses.

These studies bring to the discussion the dependency notion of data and the primacy of data at a certain point in time. Given the previous discussion, Yang (2003) emphasised an appreciation of "*the context-bound explorations"* to reflect on the intellectual actions with a cross-reference to its previous or following actions whether these actions are in verbalizing or drawing mode of action. This would trace the subjects reasoning with respect to the design situation and events over time, not only to reflect on past actions but also to anticipate further actions (Yang 2003). Thus, the standard for context bound coding is: *"Categories* *should not be single, rigidly determined and detached, but multiple, fluidly bounded, and synthetic."* (Yang 2003, p.108).

The complementary verbal and visual data complicates the analysis in terms of coding, yet has great value in that it makes the design process more explicit in terms of goals, problems and solutions. The dynamic progression of the video-audio recordings emphasise design conversation, with respect to design process interlinks between the three behaviours of visual thinking; looking, imagining and drawing.

4.4.3 Design protocol analyses

Analysing design activity involves the analysis of two aspects of thinking, explicit and implicit thoughts through externalisation (verbal and visual) (Bilda 2006; Tang 2001; Suwa and Tversky 1997; Akin and Moustapha 2004). The explicit constituent of the design thought seems relatively easy to trace, document and analyse. However, tracing design externalisation, visual and verbal, complements the thought at that point in time. Although it seems problematic it provides objective grounds for segmenting and coding the transcriptions in a context-bound data approach (Yang 2003).

Schwandt (1997 p.21) defines content analysis as "*a generic name for a variety of means of textual analysis that involve comparing, contrasting, and categorizing a corpus of data*" – essentially any data in the form of text (transcriptions) or "events". If the analysis emphasises the systematic approach of content analysis by quantifying the coded categories then this is a classic content analysis. In contrast, the contemporary form of content analysis emphasises both quantitative and interpretive analysis of the meaning of data. Based on Schwandt's (1997) definition of content analysis and from a qualitative research perspective, by considering both means of analyses, quantitative means of describing the coded content, and interpretative means of data analysis, protocol studies analysis can be seen as bridging classic and contemporary content analysis in its qualitative nature. Through context (content) analysis, the codes are assigned and arbitrated.

The researcher's knowledge and experience are used extensively in relating what is explicit through reflection to its constituent in the externalisation of thoughts, yet this remains hypothetical and relatively subjective. However, what makes studying design activity a well-situated task is the continuous externalisation while designing which has to be documented in any mode or form for analyses.

In the context of think-aloud methods, segmentation and coding are necessary procedural steps of analysis. Van Someren, Barnard and Sandberg (1994) argue that the segmented protocols can be treated as raw data and the coded protocols as data. The transition from raw data to data requires two main activities: dividing the protocol transcription (audio/video) into segments, and adapting and revising a coding scheme that suits the study's theoretical framework, to code and categorize what is going on in a segment of activities. At times, the revised code will summarise more than one activity of the design session. The coded protocols are data in the sense that they can be compared within a coding scheme, between the coding schemes and among various cases. These are quantified numerically in relation to their formal category, sub-categories or time (duration) factor (Tang 2001; Gero and Tang 2001; Atman, Turns and Adams 2005). This quantitative approach is the most common in design protocol analysis (Brereton et al. 1996). For example, this approach can focus on describing designer interaction through design process acts and design intents (assigned codes) (Cardella, Atman and Adams 2006; Ataman 2000; Gero and McNeil 1998). Besides, these codes can be modelled (Jin and Chusilp 2006) in relation to hypothetical knowledge claims, or cross-tabulated with other coding schemes (Cardella, Atman and Adams 2006).

4.4.4 Linkography

Design protocol encoding can be approached from a different analytical perspective to code the conceptual dependencies between design ideas (design moves). From the work of Mazijoglou, Scrivener and Clark (1996) on structuring drawing development, alongside the sequential relationship between a given /former drawing and the later drawing, there is a reference to the development of this drawing and its refinement. At the same time, the drawing transition network represents the flow of movements between drawings during the design sessions (Mazijoglou, Scrivener and Clark 1996). Again, this flow of conceptual/perceptual movements could be traced within the session's linkograph. Linkography is a graphical structure that retains the conceptual- perceptual relations between "*design moves*" (Goldschmidt 1995, 1997, 2003) or "*design ideas*" (van der Lugt

2000; Bilda 2006; Bilda and Gero 2008). Goldschmidt defines a design "move" as: "*an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed*" (Goldschmidt 1994), or "*a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move*" (Goldschmidt 1997).

The developmental aspect of structuring the drawing into a network is to some extent related to Goel's notion of transformative conception of refinement and development, which was utilised recently by Cai, Do and Zimring (2010) to investigate the impact of precedents on design and on the micro level of the design process.

4.5 Summary

In summary, this chapter has described the most suitable methodologies for this thesis objectives and propositions. From a process oriented view, two approaches were reviewed: case study and protocol study, in terms of features, data collection and limitations. This chapter argued that these approaches are the most suitable for achieving the research objectives and to emphasise the need for multiple methods of data collection as a means to develop a thorough understanding of CAAD effect on design processes at two levels of interaction: macro and micro level of design activity. More specific and detailed decisions and definitions are presented in the following chapter where the main decisions for data collection and analysis are outlined, based on the research purpose, setting, level of inquiry, and sampling frame.

5 Research Approach

This chapter describes the methods that are used to achieve the aim and objectives of the thesis. This chapter also sets out the empirical framework for the thesis' main studies.

Methodologically, the factors that determined and defined the conditions of this thesis' empirical studies are:

- the phase of the design process (conceptual),
- the level of the sample's expertise in design and CAAD, and
- the depth of inquiry into the research questions.

The first section presents the process of data collection over two phases of exploratory and primary studies.

5.1 Data Collection Process: Phases and Methods

The design research and methodology review established a "mixed methods" approach and two possible techniques for the purpose of this thesis. The research time line consisted of two stages of data collection: an exploratory and a primary stage.

In the first stage, two studies were planned and piloted. The first study employed a questionnaire survey and the second employed the think-aloud method (during a design task). This stage determined the design of the empirical studies contained in this thesis.

In the second stage, three studies were conducted, the first employed a cross-sectional survey, the second employed a structured reflection and the last employed a design protocol study.

The exploratory stage objectives and results are presented in the following section. The primary data collection process, the studies' design and structure are presented in section 5.2.

5.1.1 Exploratory stage

As part of the exploratory stage of this thesis, two studies were piloted at an early stage of data collection: a questionnaire survey and a think-aloud method, intended to address the methodological issues of the selected methods within the research context. Figure 5-1 shows the timeline and the sequenced blocks of data collection, analysis and design revision.

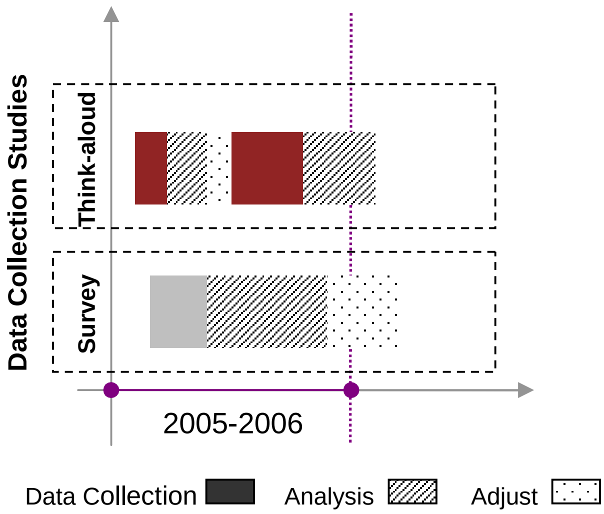


Figure 5-1 The exploratory stage of data collection and methods.

Through this stage, two studies were designed and piloted on the targeted sample. The feedback gained from the exploratory stage was useful for planning the primary studies and establishing other methodological propositions, such as the sample group. The data collected from the pilot study is summarised in Table 5.1, which was analysed and reported in Salman, Laing and Conniff (2006).

Table 5-1 Exploratory stage data collection.

Data Collection Phase	Methods	No of participants	Methodological Objectives
Exploratory	Questionnaire Appendix B1	7 responses from architectural technology 4th year students, 27 responses from master of Architecture students.	Sampling frame Questionnaire design (time required, format and readability) Describing the sample
	Think-aloud	2 Protocols (4th year student, Staff member)	The setting and the created impact The design brief suitability Changes in the procedure

In the following section, the pilot survey is presented, in terms of design, procedure and feedback. Then the think- aloud method is presented in section 5.1.3.

5.1.2 Questionnaire Survey

At an early stage of the research, some data from the targeted sample was collected for the following research objectives:

- To describe the targeted sample in terms of the contemporary context of the study and their practices in using CAAD.
- To delineate the boundaries (which could not be changed) of the generated answers, that is what sort of relationship does the targeted sample have with respect to CAAD practices at the early phases of the design process, and
- To test the design research terminology (reflecting on the gap between design research literature and the student's world) within an educational context.

Moreover, the questions and the language they employed were tested with respect to (1) clarity: the sample's understanding of the language used in design research studies (bridging the terminological gap), (2) relevance: are the proposed questions adequate for the survey purpose? And finally (3) simplicity: the time needed to fill in the questionnaire (the questionnaire is inserted in Appendix B1).

From the above objectives, a questionnaire survey was emailed to final cohorts (2005-2006) of architectural design and architectural technology students (the preliminary results were presented in Salman, Laing and Conniff 2006). A total of 34 responses were received: 27 architectural design students and 7 architectural technology students, as shown in Table 5-1. The resulting revisions focused on the questionnaire structure by reducing the general open questions and the final sequence was revised. Moreover, based on the responses, posing new questions was critical. On the other hand, an overall decision was made for a follow-up study that would provide a context for the survey's theoretical responses, to mirror its "real context" of evolution. This would provide a more reflective view of "how" and "why" questions rather than just "what" questions and mere opinions. The answers required some context to be as representative as possible of the nature and structure of the studio. However, the pilot survey helped in describing the sample group in terms of their design skill variation and computer use tendencies and patterns (this had particular importance on the researcher's situation in the studio's modern context as an observer, and in familiarising herself with modern design practices and this year's model of learning). The final survey design is described in the primary data collection in section 5.2.

5.1.3 Think-aloud method

A pilot study was conducted for both practical and technical objectives and was carried out on two different participants: a final year architecture student and a staff member with a degree in architecture technology.

The practical objectives included:

- for the researcher to become familiar with protocol study procedures.
- to determine whether undertaking such experiments would be possible with the schools' available resources and whether further resources were required.

The technical objectives of setting the (an) experiment in terms of:

- the balance between subject position and camera position versus the recorded screen and camera position.
- the video camera technical settings, and
- the required time to set up and conduct the experiment.

Finally, the research objectives included testing the protocol study instrument, the design brief (A gathering space brief, in Appendix D1, p. 370) and its efficiency (the design problem level of complexity) in eliciting "*good data*". This was proposed through the assigned task which "*should be difficult enough*," but can be solved in *"an automated way"* (van Someren, Barnard and Sandberg 1994).

In addition, the research objectives looked at whether participants would comply with what was asked from them in terms of: (1) the experiment guidelines, (2) the proposed design brief clarity and any absent information, and (3) the available CAAD software. Moreover, as part of this phase's explorative nature, some of the research propositions were looked at through the derived data. This helped in

clarifying design protocol analysis; that is the applicability of previous analytical frameworks, for example, coding schemes, design models and segmentation.
The collected protocols indicated that there were no major restrictions in terms of the practical and technical aspects of conducting such study. Both participants were positive about the experiment setting, the camera position, procedure and its impact.

Another issue raised was the time needed for the experiment. Based on the average time of the pilot (1 hour and 45 minutes), the two participants (student and staff) felt that the time needed for the experiment could be a negative factor in recruiting students. Two suggestions were discussed to reduce the total time, one of which was providing the participant with the site information though CAAD drawings of the site layout and section. The other point discussed was the site visit and the sample's level of familiarity, which may affect the participant's willingness to spend time on going to the site (campus). This helped in reducing the total time by 30 minutes, which was considered in the final design of the protocol study (in section 8.1). Moreover, the participants' familiarity with the site also helped them in proceeding smoothly through the design process.

5.1.4 Recruiting students

Recognising that the total number of students at the School of Architecture is relatively small (with approximately 100 students in the final year), the targeted sample (final-year students) was approached via different means; inviting them to volunteer by email, flyers were distributed and pinned on the final year(s)' notice boards (for Architectural Design and Architectural Technology) and in the studio(s). Others were recommended by their tutor(s) taking their CAAD skills as the main criteria.

However, recruiting students for the experiment needed more time than originally planned because of two main drawbacks. First was the time needed for collecting a single design protocol, the method (and its description in the flyers) affected the students' willingness to participate. The low response rate suggested that such a research process (experiment) is not a desirable one for the students to participate in. Thus, some of them were approached through their stage manager (or tutor); others were encouraged to volunteer by allocating financial (£10) incentives.

The second drawback was the students' skills in CAAD. In light of CAAD experimental design and participant choice, previous studies (Bilda and Demirkan 2003; Al-Qawasmi 2004, 2005; Hanna and Barber 2001) offered a pre-data collection phase of CAAD training (or a workshop) to achieve equal proficiency of the technical level in using CAAD programs. Whether the data collection method was retrospective think aloud (Bilda and Demirkan 2003), reflection in action method (Al-Qawasmi 2004, 2005), or attitudes questionnaire survey (Hanna and Barber 2001), the sample group varied in these studies from students to practitioners, and was situated in both fields of design research; design education (Hanna and Barber 2001; Al-Qawasmi 2004, 2005) and design practice (Bilda and Demirkan 2003). However, these studies never described the validity of such phased training of research design in its findings, and whether the desired level of CAAD technical proficiency was achievable through this method, as they never looked at the methods used in the training sessions and the way in which their participants used CAAD during experimentation.

Other studies (Bilda 2001; Bilda and Demirkan 2003; Hanna and Barber 2001) had a training program for the study participants as part of the preparation for data collection stages. In the current research, the level of design expertise was crucial for the theoretical framework as well as for the sampling frame of the empirical studies. According to Dorst and Reymen (2004), it is problematic to trace the level of students' expertise. Therefore, the stage of the design education is one criterion to increase the 'validity' of this study and move beyond students' differences in design abilities. The final year cohort is more likely to perform design using CAAD than earlier stages. Accordingly, a pilot survey was designed to better describe the sample's background, skills and design tendencies in terms of CAAD.

These aspects were actively adopted in the final design of the protocol study, set out in section 5.2.

5.2 The Primary Phase of Data Collection

Both pilot studies were helpful in deciding how to proceed with the chosen methods and sample. Based on the research aims and objectives, the suggested studies should enable the exploration of the design process within final-year project model under two different conditions: uncontrolled (real setting) and controlled (experimental setting). The two main studies are Case Study (questionnaire survey, studio reflection and focus group) and Protocol Study. The data generated are mostly consist of reflection, where Schön's notion of reflective practice is employed but in its methodological sense, which is considered as the most appropriate means for the targeted sample. Figure 5-2 shows data collection studies and the research timeline.

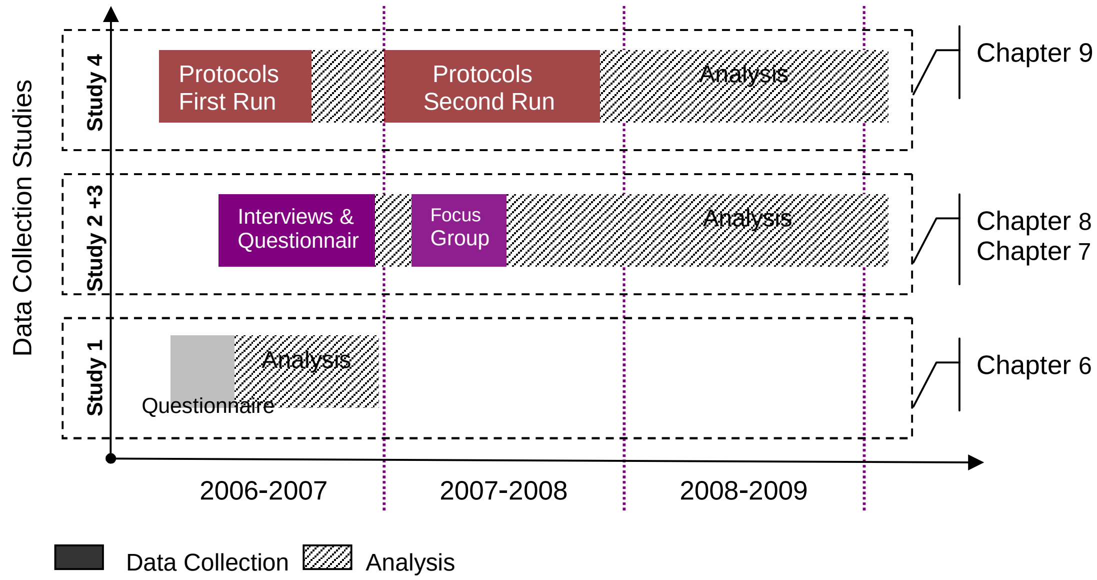


Figure 5-2 Data collection studies, methods and timeline.

The following section presents the research methods employed in the research reported in this thesis in relation to the research objectives:

- To improve our understanding of how final year students perceive_CAAD in the latter years of architectural education.

A questionnaire survey provides an overview of final year students and their characteristics with respect to CAAD use in concept design and CAAD learning methods.

- To improve our understanding of the role of CAAD programs in the traditional design studios.

Studio reflection of semi-structured interviews and questionnaires with those who used CAAD in their presentations provide a contextual overview of studio practices within which CAAD is used.

- To improve our understanding of the role of CAAD educational methods in the way it is used.

A focus group discussion was held with some of the students after the final presentation (end of year) to provide an overview of the teaching methods and discuss whether the project model was useful for learning new CAAD experiences.

- To provide an understanding of concept design process and idea development while designing with CAAD representations, and the impact of this on the individual design process.

Design protocol provides a focused investigation on the design activity that may occur between a student and the CAAD, and whether such self communication may hinder or influence students' thinking in a certain way. It also provides a structured analysis of ideas development through ideas connectedness along the design process.

- To improve our understanding of the relationship between imparting new media (CAAD) skills on "habitual" design practices.

Protocol study and studio reflection provide an overview of the relation between students' habitual practice (based on learning design mostly with traditional media) and CAAD new methods of designing.

5.2.1 Data collection studies

It has been established (in chapter three) that CAAD usage is a complex social phenomenon in the studio context. This research collected data on the same variables (student and CAAD usage) in two contrasting conditions: real and experimental, yet reflecting the same level of knowledge. According to Scott and Morrison (2006) "*the use of case study further implies that cases are not created artificially, for the purpose of the research, as with experiments."* This thesis studies were designed to test the same phenomenon by employing contrasts methodological approaches, as shown in Figure 5-3. Scott and Morrison (2006 p.17) also explained that "*The reference to the study of naturally recurring situations in which variables are not, or cannot be controlled is, therefore, a hallmark of case study."* An illustration shows the contrast conditions for the proposed studies as part of the research process, as shown in Figure 5-3. This thesis has two main studies which are the case study and the protocol study.

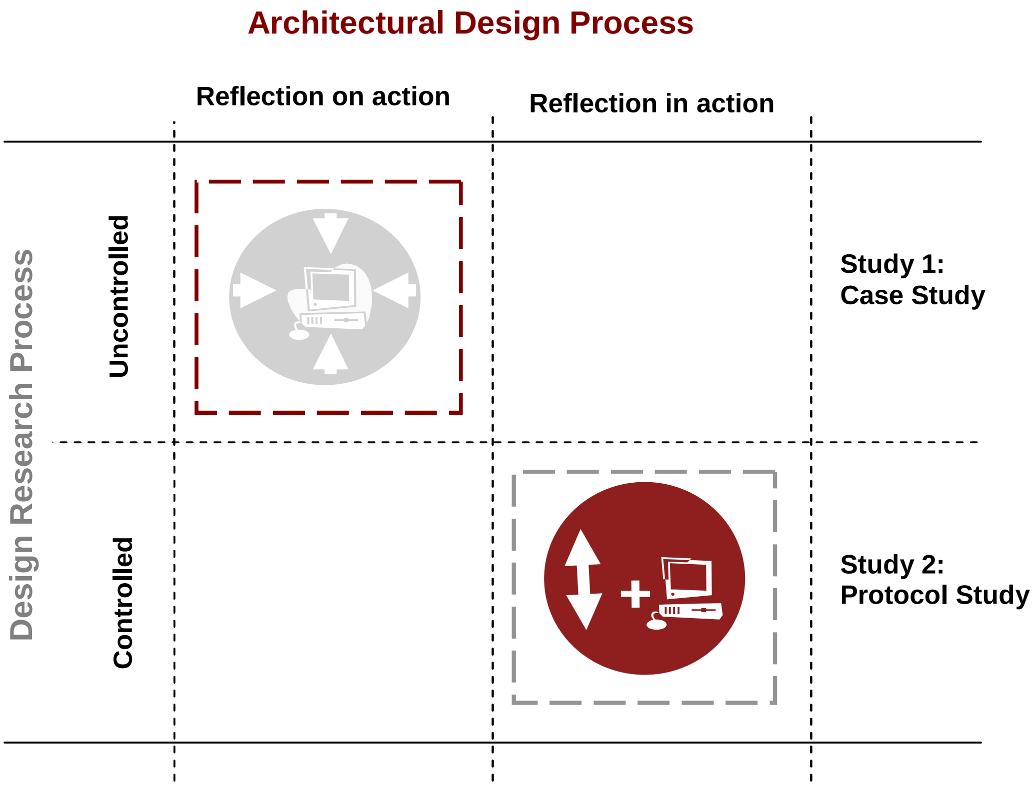


Figure 5-3 The thesis empirical studies and the theoretical framework.

The suggested studies should facilitate an in-depth (quantitative) study under the two different conditions. The study under real conditions should not interfere with the actors (students/tutors), attitudes (views or opinions), perceptions, or procedures (Yin 2003; Kulatunga, Amaratunga and Haigh 2007) of the specific context. These may, however, change under experimental conditions (the knowledge context is one for both conditions).

5.2.2 The process: Study one

The approach should allow a multiple source of data (Yin 2003) and, at the same time, complement various types of data (the language of design). Thus, a case study approach was selected over other strategies (section 4.3), whereby mixed–methods are employed. The case study data collection times and methods were decided upon in a certain structure, this is shown in Figure 5-4, that is the project model. The sub studies were structured around three main stages, the first stage is the survey, the second the studio reflection study (interviews and e-questionnaires) and the third stage was the focus group study.

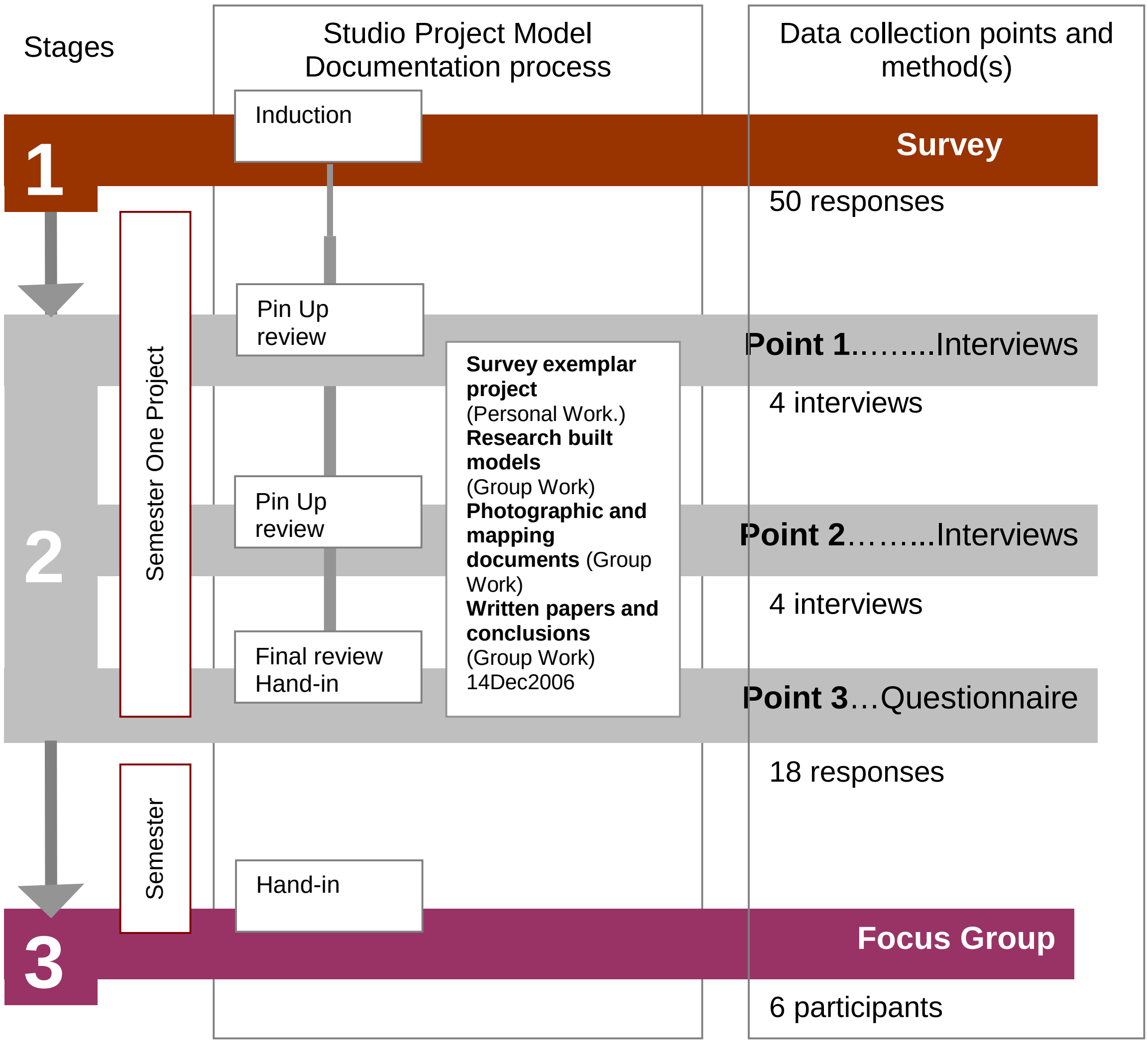


Figure 5-4 The case study stages of data collection and mixed methods.

In light of the “case study approach”, the appropriate number of participants was based on the required level of depth of data collection by which a method is justified (the more intensive the collected data, the less/ fewer cases are needed as this would complicate the analysis). Thus the “T- Design” presentation (Thölke, Hultink, and Robben 2001; Oppat 2008) is the most appropriate in the case of this thesis research approach.

The horizontal axis of the “T-Design” reflects the first phase of the main data collection, the method used, and the total number of cases of the targeted sample (cohort 06-07). A questionnaire survey was employed, and 50 responses were collected, which are shown in Figure 5-5.

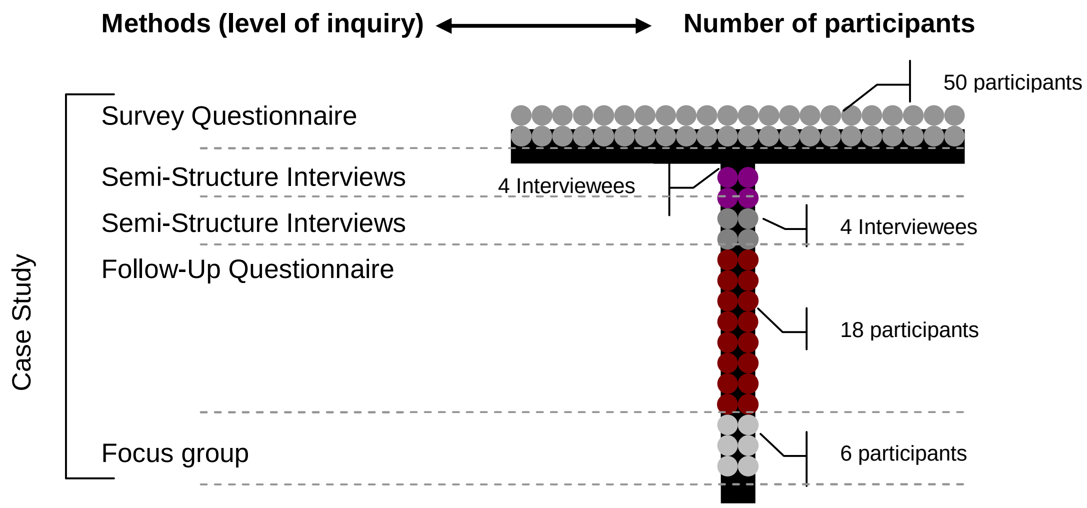


Figure 5-5 “T-Design” and number of participants (according to Thölke, Hultink, and Robben 2001; Oppat 2008).

The in-depth phase of data collection is presented by the vertical axis of the T-design, where a structured reflection study was designed to collect semi-structured interviews (eight interviewees in total, four interviewees at every interval) drawn from the survey, and then followed by 18 participants using a follow up questionnaire.

In the first and second phases of the “structured reflection”, the study employed semi-structured interviews (as a model of reflection-on-action) in the studio context. In the third phase, wider responses (reflections) were required on CAAD utilisation within the project (educational) framework. As it was the end of the semester’s project, a breadth of coverage was needed as opposed to the earlier phases where a depth of coverage was critical. Thus the study employed a questionnaire (e-mail) to complement the richness of the first generated data that the interviews yielded.

Following this, a focus group was held to reflect on the previously collected data, six participants from the same sample (final year student cohort 06-07) voluntarily attended this discussion.

5.2.3 Sampling frame

In the studies reported in the thesis, all students were at the same educational stage, thus their proficiency was assumed to be similar. The “sampling frame” for the studio reflection study was mainly based on selecting a subset of students, thus "*prior knowledge of the population to be sampled*" (Scott and Morrison 2006 p.219), was needed. Taking into consideration the qualitative nature of this study, non-probability sampling methods were selected to frame the study subset. The first sampling method was the survey. The survey outlined some of the potential cases in respect to their design skills (architectural design, sketching and CAAD skills). Following this, other selection criteria were discussed with the stage manager, which were availability and accessibility (Scott and Morrison 2006 p.221) to specify the selectable cases. These two methods were used for selecting the first phase subset, whereby the selected cases reflected on one project.

Table 5-2 The case study data collection studies, methods –Cohort 2006/2007

Case Study Sub-Studies	Method(s)	No of Cases Collected	Participants	Thesis Chapter
1: Survey	Questionnaire	50 (100%) MArch students responses	50	Ch.6
2: Studio Reflection	Semi-structured Interviews Semi-structured Interviews Follow-up Questionnaire	4 students 4 students 18 students	8 18	Ch.7
3: Focus Group	Focus Group	6 students	6	Ch.8

For the second point of data collection, "purposeful" sampling (Creswell 1998, 2009) was selected to compensate for any shortcomings of the first point sampling, such as the project type and size. Therefore, the decision was made to cover cases which were designing another project type, taking into perspective: the sample's survey, CAAD related practices and project type. Changing the sampling frame took place in the studio after interviewing the first phase cases, upon the researcher's observations and projects' review. Thus students' project review informed the selection of whom to include in the second phase upon their representation.

The third phase questionnaire was arbitrary; the objective also was to obtain various CAAD based practices and project types. Table 5-2 shows the methods, overall data and the selected cases (fourth column from left) in relation to the study. The following sections present the four main studies in terms of design, methods and procedure.

5.3 Study One: Survey

As mentioned previously in section 5.2.2, a questionnaire survey was used to describe the final year students' characteristics and their attitude toward CAAD's designing support during the early phase of the design process, and to build a knowledge base for the case study.

In light of the pilot survey (in section 5.1.2), the question sets were revised and new questions were added. The purpose of the revised version was to describe the final-year students as the main "unit of analysis", from which the two other studies obtained information. Thus, the context is crucial to get the meaning of the sample's attitudes toward CAAD, which was another reason for a qualitative approach.

With respect to the study context, the sample's design knowledge (skills and methods) is related to the pedagogical approach of the Scott Sutherland School. However, there is a high probability that this study sample may represent part of a bigger population within UK schools of architecture that embrace a similar pedagogical approach/philosophy. At the same time, the results would deviate if the same survey were to be employed in schools of architecture which embrace digital theories and computation. The sample was final year students (Master of Architecture) cohort 2006-2007, who studied architecture for at least four years and used CAAD mostly for drafting and presentation prior to the research.

5.3.1 Survey description

The questionnaire (see Appendix B2, p.353) was divided into seven sections as follows:

1. *Participant's Background Information*: section one asked about students' profile (ID, gender, age and IT access). The purpose of this section was to

describe the sample as a final-year student and if this information has any effect on the other responses from the other sections.

2. *Designing general skills*: section two asked about students' designing skills (design, sketching and CAAD), learning sources, how long they have been using CAAD, general views of CAAD in relation to conceptual design and finally they were asked to describe the use of CAAD while designing in relation to the design process phase. The purpose was to define the sample's general knowledge of design and CAAD to know what effect it has on how and when CAAD is being used. What is the guiding mindset behind the tendency of using CAAD?
3. *CAAD Use and Programs*: section three asked about how students would define CAAD with respect to the dualism of being a designing or a drafting tool. The purpose was to map the relation, if any, between how CAAD is perceived and the type of CAAD (professional systems) programs.
4. *CAAD Use In The Early Phases Of Design*: section four asked about how CAAD is being used in relation to the conceptual design phases and what sort of support this use could bring. The rest of the questions were open ended through which the students were asked to specify other effects of CAAD, whether positive or negative and why they thought that way.
5. *Design Medium Preferences*: section five asked likert and semantic differential questions about drawing activity in relation to ideas development and CAAD use, before asking multiple questions about design medium preferences with regard to sketching, modelling and CAAD and the potential effects.
6. *3D Models (Physical or Digital) In The Early Phase of Design*: section six asked the students multiple questions about 3D modelling. Then it was asked how often models are used, at which stage they are used, and also the effects of using such medium may have. The purpose of this section was to specify the perceived differences between traditional and digital modelling.
7. *CAAD Teaching Methods:* The final section asked multiple choice and open ended questions about CAAD's teaching methods. The purpose was to reflect on the teaching methods of CAAD in architectural design schools.

5.3.2 Procedure

Reflecting on the first run difficulties in getting a satisfactory response rate, this run was organised with the stage manager to distribute the survey questionnaires at the studio at the very start of the first semester (2006-2007). The survey was completed using a paper-based approach. It was explained that these questions were for research purposes only and the answers would be treated anonymously; participants were, however, asked to write their matriculation number (ID) and indicate whether they were interested in taking part in a follow-up study. The intention was to identify appropriate participant(s) for the other planned studies, with respect to the sample willingness and motivation to use CAAD in the conceptual design process. The survey analysis, results, and conclusion are reported in chapter 6.

5.4 Study Two: Studio Reflection

Data collection intervals were defined as points of reflection, (as shown in Figure 5.4, stage 2 of the case study). These points were based on the project structure of the studio and its main events (pin ups, reviews and hand in), as shown in Figure 5.6. The purpose of this study was to explore CAAD utilisation in the studio context in relation to the traditional model of architectural design project and the design process phases of problem identification, analysis, synthesis and evaluation. Therefore, the data collection methods varied upon whether the data is collected at the beginning of the studio design process, in the middle, or at the end. This study was a longitudinal study in the context of looking at the early phases, as well as the later phases of design conception, for an extended period of time. Achten and Reymen (2005) coined this methodology as structured reflection.

5.4.1 Procedure

This study, in comparison to Reymen's framework, can be described as semi-structured rather than structured; because it was structured around the project reviews (critic, pin-up) time intervals that were set initially by the stage manager and the semester project schedule. Although preliminary dates were set in the project(s) induction brief, there were shifts, because of either tutor's feedback (more work needed to be done) or students' requirements (that is not enough time to present). Therefore, each pin up review through the semester project (academic design process) has identified explicitly its validity for reflecting where new changes have been made or old ideas have been dismissed and what is the context for the changes made. There is no indication whether the time range would change the validity or quality of the participant's reflection but arguably it may be intensified in terms of quantity. The conceptual change can be traced within students' reflection (data) as long as there is progress in the design process. It is important to bear in mind that the study context is academic so the changes would take place at a slower pace than in real practice contexts.

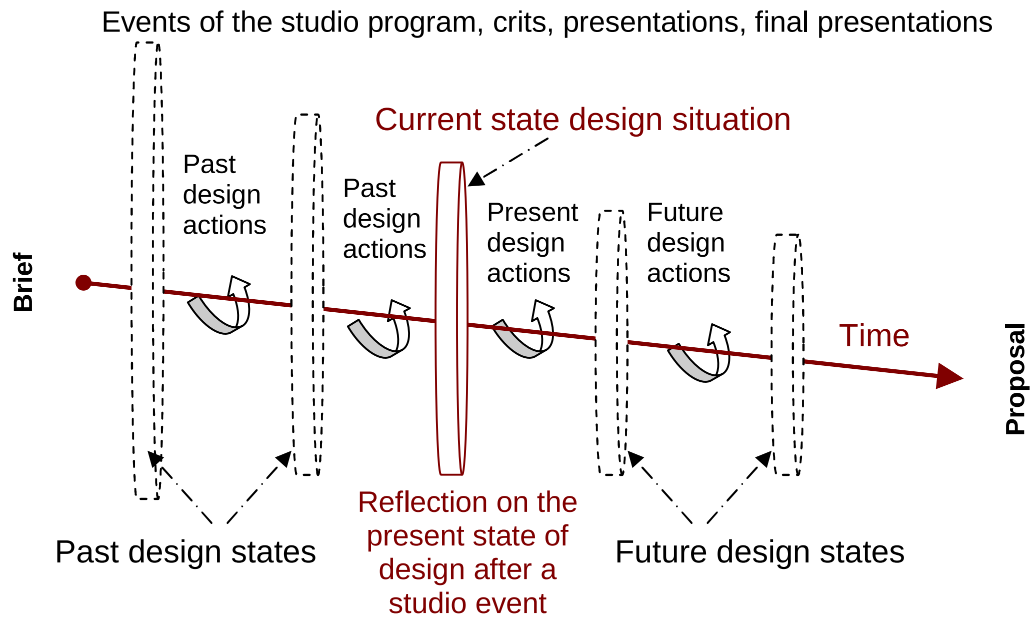


Figure 5-6 Reflection on a design situation alongside studio events (adapted from Reymen et al 2006).

Semi-structured interviews were employed at the two early points of reflection to collect students' views, attitudes, and experiences. These were conducted after the review (critic) intervals of the studio work, whereby the researcher got an idea of the work done before the interview was conducted and probed both the work done and the work needed to be done.

5.4.2 1st Point and 2nd point of semi-structured interviews

The interviews were set to elicit the students' reflection on the studio project, the design media used (by the student) or suggested (by the tutor), and the learning outcomes (proposed and achieved). The question style was mainly open ended to give students the opportunity to elaborate on their studio experiences and the progress they made with respect to the design process, media and feedback they received. Thus, the question style was conversational, informal yet relevant, and semi-structured for two purposes: to enable the embedding of real context changes that can occur in terms of the design phase or event, but also to provide comparable grounds among the interviews (Flick 2009). For example, after a studio review, the questions may change to enquire into the critical remarks that were observed through that review in relation to the specific case. At the same time, the context and events are common to all the cases and this would allow the researcher to compare, relate and justify. (The question sets 1 and 2 in Appendix C1 p.360, and C2 p.362). The interviews took place in the studio while working. It was of interest to observe the connection between the work being done and the data generated.

5.4.3 3rd Point of follow-up questionnaire

The purpose of the e-questionnaire was to triangulate what content analyses of the (semi-structured) interviews' transcriptions may have revealed in terms of the earlier phases of this study data collection. As it was the final phase for the semester project, a unified questionnaire was sought to narrow down the focus of this phase data analysis and bring common grounds for comparison and progression with the two preceding phases. Thus, the questionnaire design considered the earlier semi-structured questions to set modified questions that were probative of the reached level of understanding (for both the learner and the observer/researcher). (The questionnaire is presented in Appendix C-3, p.365 of data collection methods).

The questionnaire format was mainly open-ended, reflecting the qualitative nature of this study. This gave students the opportunity to describe, specify and criticise what they did. However, some of the extracted themes were tested in multiple-choice questions.

5.5 Study Three: Focus Group

Assumptions have been developed throughout the research, and a focus group was used to challenge, debate and examine emerging findings (Krueger 1998; Fink 2009), (as shown in Figure 5.4, stage 3 of the case study). A focus group is a data collection procedure consisting of a group interview or discussion (qualitative approach) to access memories, feelings and perceptions concerning a specific focused topic (Krueger 1998). Within Schön's theoretical context of reflection on processes, focus group *data* can be seen as *reflection-on-practice* (Schön 1983; Reymen 2001).

The study plan was set to undertake a group discussion, where participation was voluntary, to listen and gather information from the same sample that have certain characteristics in common so as to understand how they feel and think about issues such as the relative impact of CAAD on their conceptual design, and CAAD learning methods. Another goal was to raise and further discuss some of the results from earlier surveys.

5.5.1 Procedure

The procedural steps to organise the event were as follows:

- designing the questions in relation to the previous phases of data collection (structured reflection and observation).
- piloting the questions at the last interview series and gain some feedback.
- deciding on what day and time would be the most appropriate for the event to be held. This was done by students' consultation (sending an email asking the student to tick the most appropriate time that the student would prefer, based on their projects' review schedule).
- providing the focus group "guide" (The questionnaire is presented in Appendix C4,p. 368), for use by the facilitator, and
- disseminating an invitation electronically by e-mail and hard-copy flyers, with the event details, time and place.

5.6 Study Four: Protocol Study

Design Protocol studies provide direct data on the ongoing thinking processes of architects and designers with different levels of expertise (Dorst 2004; van Someren, Barnard and Sandberg 1994; Cross, Christiaans and Dorst 1996). Such data provide information about the reasoning structure that otherwise could not be obtained by looking at the process result. Protocol study analysis enables the understanding of how they arrived at the proposed design, what sorts of difficulties they faced and how they managed the design brief constraints (task).

Based on the work of Gero and McNeill (1998), Bilda (2001, 2006), Bilda and Demirkan (2003), Akin and Lin (1995) and Goldschmidt (1996), a theoretical framework is outlined which could achieve the thesis objectives. A visual / verbal analysis is sought for structuring design protocols, to retrieve the rational structure of each design session for each student.

It is recognised that the design situation is influenced by the design task (brief) at hand and the design medium (Coyne, Park and Wiszniewski 2002). These two aspects of *design* problem solving set the constraints for the proposed session's design activity. The participant would have to compromise between the design task constraints (design brief, site) and the medium constraints (hindrance, accuracy, preciseness and scale).

The second drawback of design protocol study is the students' skills in CAAD. To effectively understand how CAAD affects and changes the design process, these variables had to be minimised in terms of: architectural design skills, and CAAD use skills (Al-Qawasmi 2004). These variables form a triangular shape that is often distorted by the differences between students (sketching, design and CAAD) 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 CAAD systems in solving a design task at the conceptual phase may initiate a shift in their attention slightly from CAAD working methods into architectural designing methods.

Table 5-3 Protocol study data collection (2006-2007).

Study	Method	No. of participants	The selected protocols	Thesis chapter
Protocol study	Think-aloud	*1st run -2006* 9 Participants	SA1, ST3	Ch.9
	Think-aloud	*2nd run-2007* 3 Participants	SA2, AT4	Ch.9

This was noticed as a result of some of the collected protocols. Some of the participating participants could not fulfil a satisfying result in terms of the 3D conceptual requirement (task) because of their level of CAAD expertise. The variety of the collected design protocols quality made the comparison between the cases almost impossible and time consuming. Thus selection criteria were set to select which data and cases are the most appropriate for analysis and reliability. Cases selection was based on two criteria:

(a) the protocol's verbalisation style, which affected the ability to talk while designing thus having more pauses than the average (c.f. Tang 2001).

(b) the quality of the participant's conceptual process; the participant could not fulfil the design task requirement or all the requirements.

According to the mentioned criteria, four protocols were selected for analysis and were used to validate the proposed encoding schemes.

5.6.1 Protocol encoding schemes

The choice of the schemes adopted for encoding these research protocols were based on the knowledge claims made in chapter 2 and 3 and, accordingly, changes or modifications were made to the original. These will be emphasised for each scheme and presented in sections a, b, c, d and e.

The final schemes used were developed through an iterative series of revision by testing the applicability of each scheme against the selected case which were compared to the other cases or the previously coded cases.

To reach a logical coherence and accordance between the coding schemes and the coded data, all codes were applied to the selected protocols to ensure its applicability. This was done at the end of coding every protocol. This also helped in evaluating the collected protocols with respect to its course of action (process) instead of the produced designs which were reduced to four valid protocols for the purpose of the research objectives.

5.6.1.a Segmentation

Segmentation is the basis for all the other encodings. The theoretical basis for segmentation is based primarily on the work of Suwa and Tversky (1997), Purcell and Gero (1998), and Suwa et al. (1998), which retain to the participant intentions of design and other explicit strategies. As discussed in section 4.4.1, segmentation is context bound (Yang 2003), meaning that the division is bound by the immediate context of the verbal data as well as in the visual data. Initially segments are coded on a general level of division by time stamps; when an attention occurred and when it shifted or completed. Table 8.1 shows an example of the segmentation of SA1's design protocol.

5.6.1.b Process-oriented coding

In general, the process–oriented method in encoding design protocols was developed by a number of iterative studies carried out by Gero and McNeill (1995), McNeill and Edmonds (1994) and Purcell et al. (1996) to be used to analyse engineering design sessions. These studies were the basis for Gero and McNeill's (1998) published work, as this study projected a framework to structure the rich unstructured data to obtain a detailed understanding of the design process-grain size analysis - in which a design process is captured. Gero and McNeill (1998 p.23) asserted, "*A framework can be brought to the design process by considering the designer's activity as consisting of a sequence of actions or micro strategies each typically lasting for a few seconds or tens of seconds. The design process can be viewed as one in which the designer engages the design problem by calling upon a repertoire of micro strategies.*" The reader is directed to Appendix D-3, p. 373 for the full lists of Gero and McNeill (1998) coding and the adapted list used in the data coding of this thesis.

5.6.1.c Level of abstraction coding

This was discussed previously in section 2.4. This research adopts the classification of Purcell et al. (1996) on levels of abstraction developed originally to code the mechanical engineering design protocols, to be used afterwards in architectural design protocols (Bilda 2001, Bilda and Demirkan 2003) and many other design disciplines. This initial classification consists of four main levels of problem consideration: (0) denotes "*the top level of abstraction where the designer is considering the problem as a whole*" that is in relation to the whole site, (1-2) denotes the other levels of the partial problem relative to the whole problem "*sub-problems identified by the designer*". Level (3) denotes the detail level of abstraction. In the light of the above discussion, when a level of abstraction is coded in CAAD a distinction between the level of viewing and the level of abstraction should be made.

As previously discussed in section 2.4, the level of abstraction is dynamic and changeable from moment to moment reflecting the partial problem that is being solved or emphasising one aspect of the problem at hand. Defining the level of abstraction is easier with sketching representations, as the drawn sheet reveals at what/which level the designer is working on by the part or the sub-problem being drawn (considered). However, CAAD view manipulation could flag a change related to conception, especially since CAAD's dynamic representation (navigation and viewing options) that is, zooming in and out has various viewing levels. The viewing level is extremely different from the level of abstraction, as the latter is related to the cyclic process of designing, but the former is related to the medium characteristics (computer program) and is concerned mainly with checking the perceptual aspect of a drawing / practical.

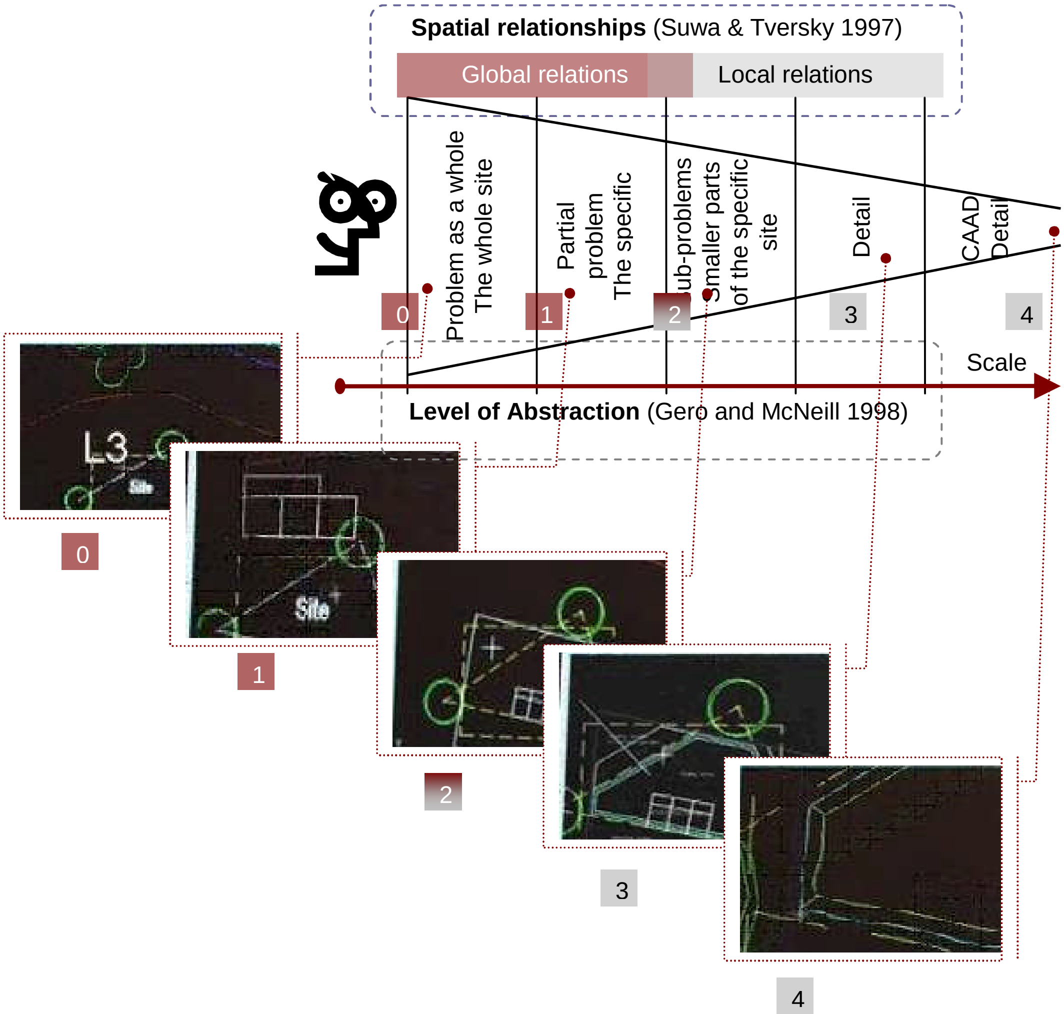


Figure 5-7 The overlap of the two propositions; spatial relationships (Suwa and Tversky 1997) and level of abstractions (Gero and McNeil 1998).

Level of viewing marks a tendency to check what has been drawn or to change what has been drawn, so that alteration becomes evident. As a result of this discussion another level is added to see if CAAD detailed and accurate environment would affect the student's perception towards a more detailed level that is deeper than level (3) that is, level 4. As shown in Figure 5-7.

To date there has not been research on characterising early CAAD representations as having lateral or vertical transformation. This thesis will explore this issue within protocol studies. This aspect is much related to the argument that CAAD may shift the level of abstraction from higher levels of conception to lower and more detailed levels of conception.

5.6.1.d External representations

A drawing has been defined by Mazijoglou, Scrivener and Clark (1996) as "*a continuous sequence of drawing activity terminated by a change in drawing act type or a detectable interruption in drawing*". Drawing acts that students perform while using CAAD are encoded within each segment of the protocol (the coding scheme is appendix D-3, p.373), whether it was CAAD based or non-CAAD based acts. Figure 5-8 shows the developed coding structure.

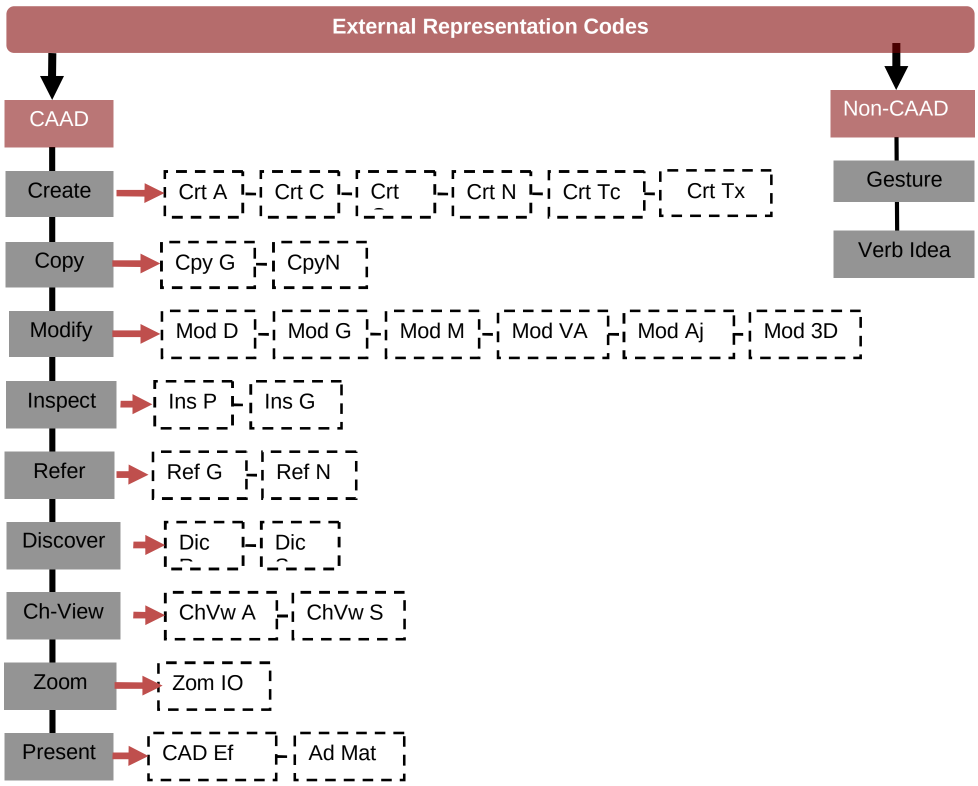


Figure 5-8 External representations coding structure/tree.

According to the designers' perceptual actions, CAAD depicted objects are not static as in other kinds of drawing. In addition, *viewing activity* of CAAD objects or the depicted entities is interactive while in the other types of drawing it is also static. It is suggested, in the CAAD environment, that CAAD users tend to move the depicted objects to different places because CAAD working methods compel them to do so, and thus a designer might figure new relations or new possibilities that he did not think of previously.

5.6.1.e Linkography coding

In the current study, a design move is determined by any action that has changed the status of the design into a new status that can be traced externally. Those actions could be decisions, goals, constraints that were set and met successfully. The protocol segments were the main unit for coding design moves. But the segments included more information that a design move would entitle. Assigning design moves was based on Goldschmidt's (1995) definition of a design move. By considering the visual and verbal context of every segment against design moves were assigned in the same platform of Transana, emphasising the context of its being and its potential connectedness along the design process. Most of the segments though revealed one to two design moves at the most. A design move then became equal to an idea that had been externalised verbally or graphically during the process. As a result, the number of design moves became smaller from the initial number of segments for every protocol.

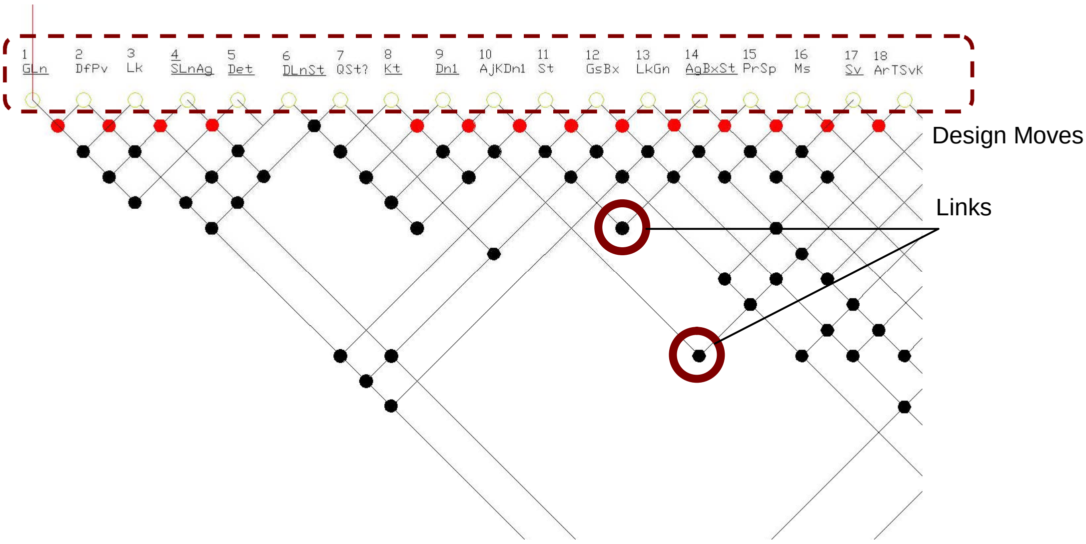
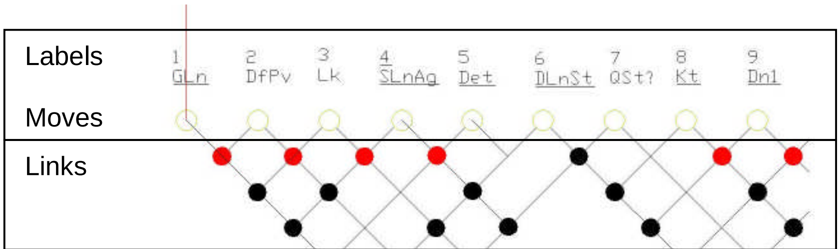


Figure 5-9 An example of coding design moves and links (ST4 in Appendix G-7).

Although, Goldschmidt stressed common sense as the main approach to determining the link between two or more design moves, she mentions that this, in practice, means that: *"...a link between two moves is established when the two moves pertain to the same, or closely related, subject matter(s)*..." (p. 90). Other linkographic studies have shown that utilising common sense seems to be a tentative technique to elicit the relations of latter/former moves. Other researchers like van der Lugt (2000) have strengthened Goldschmidt's notion by defining indicators for judging the commonality between design moves. He suggested that the common sense reliability could be enhanced by developing indicators for links; in addition to the similarities in content (Bilda 2006) and argued that "a *link is present, even though the subject matter between these two ideas is not closely related*". Also by associating links, the potential contribution of every move along the design process (line) is decided against all the other moves that have been assigned as design moves.

However, there are two difficulties in associating the links along the design timeline. The first one is how to track the content of each move (each segment could have more than one sentence) and the other difficulty relies in the association between links that occur further down the line of the design. To overcome these difficulties Bilda (2006) has suggested a means to aid the analyst's common sense, by employing a word search to find any commonality in meaning of such distinct design moves (segments). This includes more than one run through the questionable segments and links.

The coded links are categorised into fore-links and back-links. Each have a different meaning with regard to the design process. Back-links are links that are related and considered as a *concluding move* "*that summarises or evaluates points raised in the exploration"* (Goldschmidt 1995), and Fore-links *"record the path that led to a move's generation, while fore-links bear evidence to its contribution to the production of further moves"* (Goldschmidt 1995). The total number of back-links and fore-links are equal in every linkograph but different on the level of a design move.



Backlinks: move 2 has one backlink to move 1, and Move 4 has three backlinks to move 2, 3 and 4.

Forelinks: Move 1 has three forelinks to move 2, 3 and 4. Move 2 has two forelinks to moves 3 and 4.

Figure 5-10 An example of coding the forelinks and backlins of a design move.

Researchers such as Goldschmidt (2003), Bilda and Gero (2008) and Van der Lugt (2000) devised a number of measures for evaluating (conceptual) productivity and design flow. This study also uses the same measures of critical moves, link index and clusters. Goldschmidt (2003) defines "*critical move" (CM) "identifies design concepts that are deemed "successful" in the sense that the designer values them enough to devote time trying to develop the concepts or at least to promote them at various points in the protocol*". CM percentage refers to the total number of CM in a design session in relation to total number of moves. Link Index (LI) is a measure of how connected the design ideas are in a design session. In order to calculate the link index in the overall session, the total number of links is divided by the total number of moves in the design session.

5.7 Summary

In summary, this chapter has set the methodological framework and the main decisions for data collection and analysis, which were based on the proposed questions, purpose, setting, level of inquiry, and the sampling frame. According to case study and protocol study research methodologies, multiple methods of data collection were employed as a means to develop a thorough understanding of CAAD effect on design processes at two levels of interaction: macro and micro level of design activity.

The results of these studies are presented on an individual basis in the subsequent chapters. The questionnaire survey is presented in chapter 6, the studio reflection study analysis is presented in chapter 7, the focus group analysis is presented in chapter 8, and the design protocol study analysis is presented in chapter 9.

6 Study One: Survey

This chapter presents the results of the first study (stage one of the case study). The purpose of this study was descriptive, meaning that the results explain and characterise the sample for the two succeeding studies. Moreover, this study provided a prior knowledge of the studied population to support the case study sampling frame, and helped to build the case study by informing the characteristics of final year students.

The questionnaire survey was descriptive in nature but also evaluative, and this was critical in two respects. Firstly it described the contemporary student from the student's perspective by reflecting on the student's experiences and the application of CAAD, in order to support the study with contextual propositions. In addition, it provided a knowledge base for the thesis case study population, and further informed the subsequent studies' sampling-frame. With respect to students' self-assessment of design skills, the results outlined a number of potential students who have good design skills (architectural design, sketching and CAAD skills) to be approached for the studio reflection study.

6.1 Method

The surveyed sample consisted mainly of final year students (Master of Architecture) who have been studying architecture at the Scott Sutherland School of Architecture and Built Environment for at least three years with an average of one year industry experience (taking a placement), i.e. practising design for almost four years.

As was discussed in section 5.3, the survey aimed to determine how CAAD was perceived by final year students in the traditional context of architectural design education, the basis on which such perceptions were formed, and how these perceptions have affected the way the sample used CAAD programs in practice (process).

The survey responses were analysed using SPSS and MS Excel packages by performing descriptive statistics and frequency analysis (Field 2005), presented in percentages and reported in the next section.

6.2 Survey Results

A total of 50 responses (100% response rate) were received. The questionnaire took approximately 15 minutes to complete. The questionnaire results are presented in the same sequence of the main design sections as described in section 5.3.1.

1. Participants' background information is presented in section 6.2.1.
2. Designing general skills are presented in section 6.2.2.
3. CAAD use and programs are presented in section 6.2.3.
4. CAAD use in the early phases of design is presented in section 6.2.4.
5. Design medium preferences in presented in section 6.2.5.
6. 3D Models (Physical or Digital) in the early phase of design are presented in section 6.2.6.
7. CAAD teaching methods are presented in section 6.2.7.

6.2.1 Background Information

Descriptive analysis was carried out to provide a general overview of the sample to be presented in percentages. Survey responses were analysed using the SPSS package with 50 students (46% females and 54% males), representing 100% sample of the cohort (2006-2007). The sample mean age was 23 years and eight months old, and the sample age ranged from 21- 28 years old (SD 1.68171).

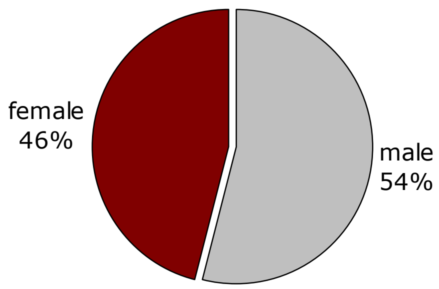


Figure 6-1 the case study sample.

The Sample had access to the following computational tools outside the school: Half of the students (50%) have personal computers, the majority (82%) have personal laptops, (84%) have installed one or more CAAD software programs, and 74% have an Internet connection. This is shown in Figure 6-2.

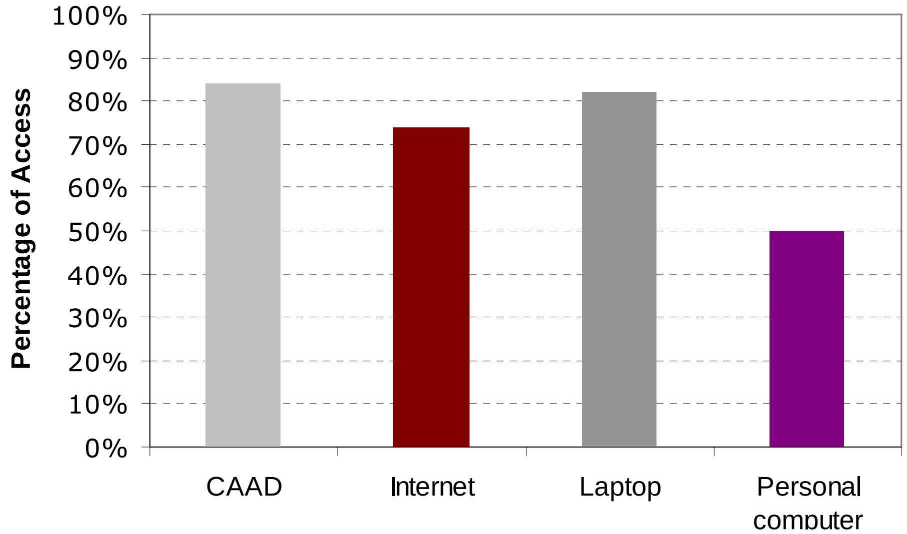


Figure 6-2 Student's access to IT

These high percentages describe the sample as motivated students that acquire access to computers at will, in spite of the fact that they are studying design with a predominantly traditional mode of teaching. The results demonstrate that students' preference to obtain a laptop is higher than obtaining a personal computer. This indicates two related aspects for consideration: the first aspect is the elective mode of using a computerised environment and the second is the open access to their design material at any time or location.

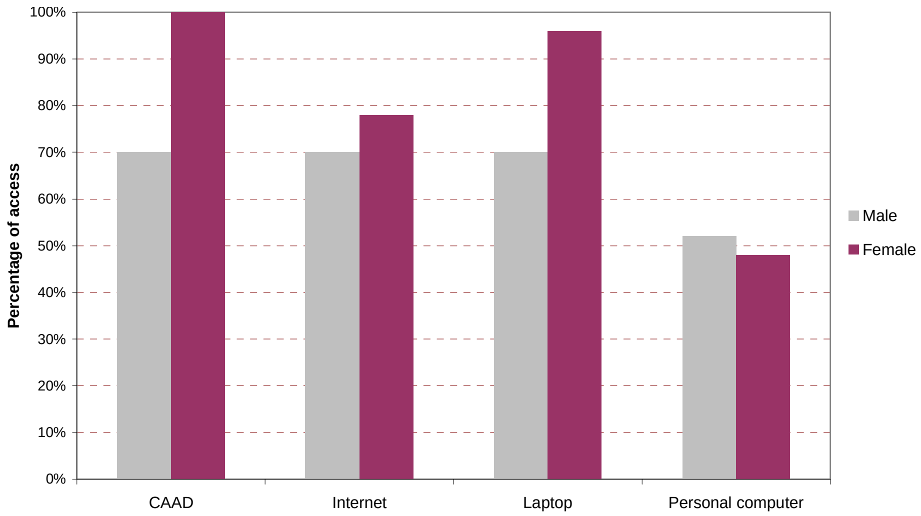


Figure 6-3 the sample has access to the following IT

Although studying gender based differences in using CAAD is not an objective of this study, it is intriguing to demonstrate that some differences exist in IT (hardware and software) possession (physical access), as shown in Figure 6-3. The possession of CAAD is higher among female students (all the female students have laptops compared to the male students). Furthermore, higher percentages of females have CAAD and Internet access compared to the male students; however, they had the lowest rate of personal computers possession. Male students have lower percentages of IT possession compared to female students but they have a marginally higher percentage of possessing personal computers.

6.2.2 Design skills

The sample assessed students' design skills (architectural design, sketching and CAAD). Students' skill "self-assessment" was measured on a five–level scale from poor (1) to excellent (5). The results are shown in Figure 6-4. The results showed that students ranked their design skills as follows: architectural design skill mean score is good (mean score of 2.98 out of a possible 5) sketching skill mean score is good to fair (2.82), and CAAD skill mean score is very good to good (3.68) and this is the highest mean compared to the other two variables. The box-plot in Figure 6-4 provides a visual indication of the students' self-assessment scores. It shows the lowest score and the highest.

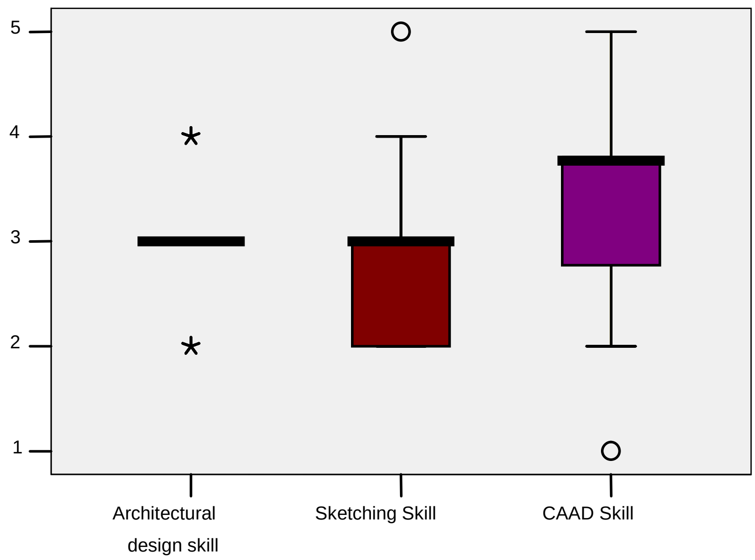


Figure 6-4 Data box plot of the sample's design skills self-assessment

Each box shows the median, quartiles (the range: the middle 50% of the scores) and outlier (an odd score) values within a category (Field 2005). For architectural design skill the scores accumulated to around 3 and for sketching skill the range of experience level was between 2 and 3, most of the scores accumulated around 3. For CAAD the range of experience level was between 3 and 4, and most of the scores accumulated around 4. It is obvious that students were consistent in assessing their architectural design skill and extremely inconsistent in assessing their CAAD skill by scoring various levels of CAAD experience within the same studying stage. This aspect should be taken into consideration in designing new CAAD courses. Normally, students at earlier stages of architectural education have various levels of skill but this is less likely to be noticed when they are at the final stages of their education.

In response to how final year students obtain their CAAD experience after at least four years of education (multiple choices were applicable), the students frequently cited personal effort and architectural practice (placement) respectively. As shown in figure 6-5, the most frequently reported sources for their gained CAAD experience were “personal effort” (62%) and “architectural practice” (56%) followed by “University courses” (36%) while 8% only reported “private courses” as one of the sources of their learning. The sources “personal effort” and “Architectural practice” show the importance of two aspects of gaining CAAD experience. One is related to self-willingness (motivation) to learn and spend time and effort to reach the intended objective and the other aspect is related to the setting and its relative design and practice knowledge to become a contextualised learning experience.

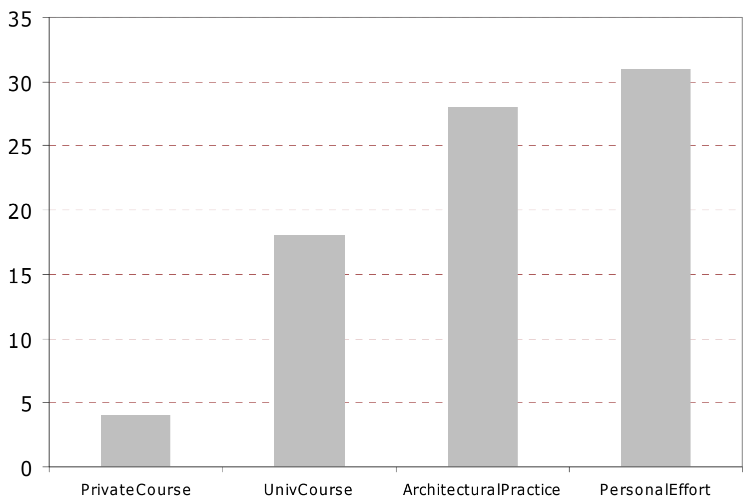


Figure 6-5 A Bar chart of CAAD knowledge sources

In relation to CAAD experience, the students were asked how long ago they started learning CAAD and whether this had a direct correlation to when they started using CAAD in design. In general, there is a direct correlation, but the responses showed two patterns. The first pattern indicated that learning and using CAAD started at the same time, as there was no gap between the two starts, which was reported with a significantly higher rate of 76%. On the contrary, the second pattern indicated that there was a gap between the two starts, as reported by 24% of the students. The gap between learning and using CAAD ranged from 2-4 years. On average, the sample had started learning CAAD 4-6 years ago and had started using CAAD 2-4 years ago. Leaving a gap between learning and actually using CAAD in design could suggest that some students (12%) need more time for recognition, although the prevalent trend is learning and starting using CAAD at the same time.

Based on the sample's background and skills, Figure 6-6 shows that more than half of the sample (58%) believe that learning CAAD has influenced their designing capability in general, and 46% (less than half) agree that acquiring CAAD skills has improved their architectural design skills. This suggests that the sample's views regarding CAAD impact on design related issues and capabilities are divided, although they share the same level of knowledge as they are at the same stage. In parallel to these views, similar percentages were obtained when asking about students' thoughts about generating conceptual design by the use of CAAD. More than half (52%) of the sample responded positively to "I do this already" and 12% of the sample "would like to do so even if they think that they are not skilled at CAAD." While 18% of the sample thought that it is interesting but they would not use it for generating conceptual design, others (16%) were sceptical about using CAAD in generating conceptual designs, either because they had never heard of it or never knew that this was possible, or never taught how to do it.

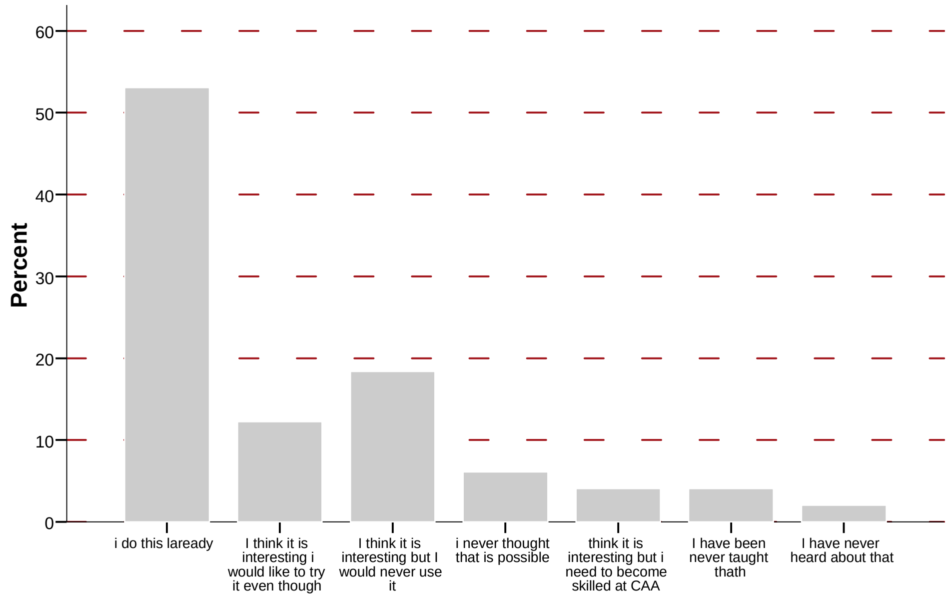


Figure 6-6 A bar chart of students' Views on generating conceptual design using CAAD

The sample's positive views about generating conceptual design using CAAD suggest that there would be many CAAD instances in conceptual design within that context that could be traced in a follow up study. However, the relatively negative views about the use of CAAD in generating conceptual design indicate that the sample had not been taught CAAD within a design-based teaching.

The majority of the sample (82%) used CAAD while designing on a regular basis, as shown in figure 6-7, whereas 16% of the students reported that they were using CAAD sometimes while designing. This shows an integrated pattern of CAAD usage in conjunction with manual and other tools of a parallel process of conception and construction.

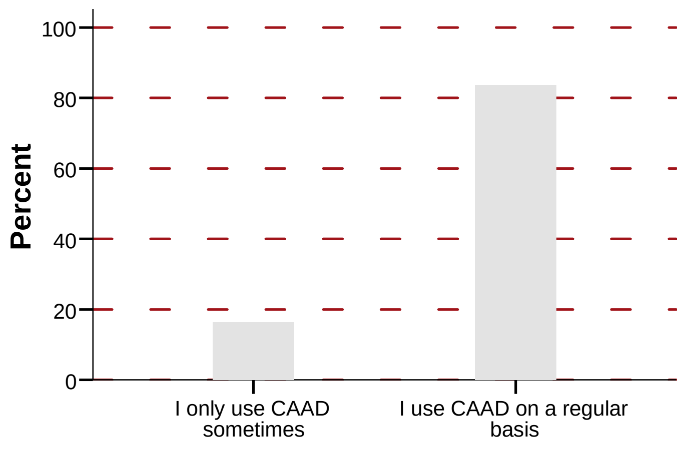


Figure 6-7 A bar chart of CAAD use frequency

CAAD use tendency is shown in figure 6-8. Sixty-four percent of the students used CAAD in both phases of the design process, the early and the final phases and (32%) of the students used it in the final phase of the design. Only 4% of the students reported that they were using CAAD in the early phases of the design for design brief analysis, outline design and final sketch design.

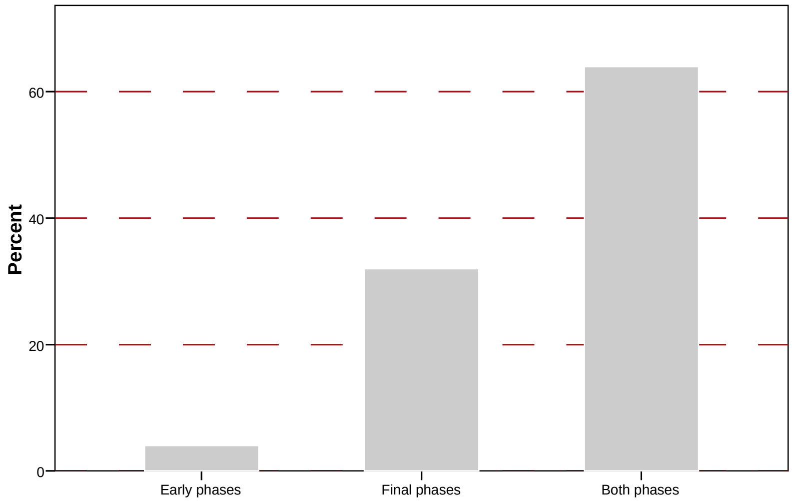


Figure 6-8 A bar chart of CAAD use

Recalling the preliminary observations from the pilot survey, (results from the pilot survey 2005/2006 were published in Salman, Laing and Conniff 2006), showed that 54% of the sample was using CAAD in both phases (early phases and final phases) of the design process and 46% using it during the final phase. Compared to the current result there is an increase of 10%, perhaps suggesting a shift of 10% in CAAD usage over one year only.

The majority of the sample use CAAD regularly in the design process and use CAAD in both phases (early phases and final phases) of the design process, whilst a significantly lower percentage use CAAD during the early phase only.

6.2.3 CAAD Programs

In response to which CAAD programs were used by the sample, (multiple choices were applicable) the most scored program was AutoCAD (100%), then SketchUp (64%) and ArchiCAD (16%). Other reported programs were 3ds Max (22%), Autodesk Viz (12%), Vector Works (8%) and Micro station (6%). As shown in Figure 6-9.

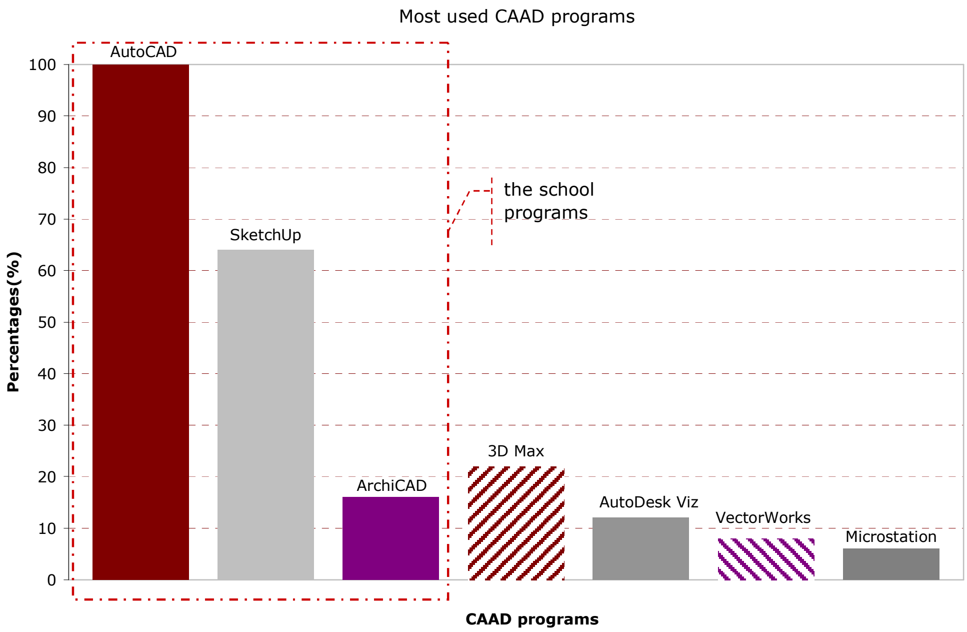


Figure 6-9 A bar chart of CAAD programs

The CAAD programs used (seven programs in total were specified by the students) were classified into CAAD programs available (three programs) at the school and other programs (four programs) that were learned outside the school curriculum, which will have an influence on imparting new skills and practices to the learning environment. Some of the programs that are dominant in professional practice of architectural design are also dominant in architectural education e.g. AutoCAD. On the other hand, SketchUp provides a different kind of program that students seem to need frequently.

However, taking into consideration the impact of the following issues: (a) the sources for the sample's CAAD obtained knowledge (personal effort and architectural practice in the case of this study sample), and (b) the rapid changes in CAAD programs and digital technology with lower learning curves, suggests that this trend (imparting new skills) will be increase over the next years (in a search for the right tool).

Considering AutoCAD's dominance in professional practice and education, Figure 6-10 shows that 46% of the students tend to use CAAD as a drafting tool and the same percentage of the students tend to use it as a drafting and designing tool. Only 6% of them tend to use it as a designing tool.

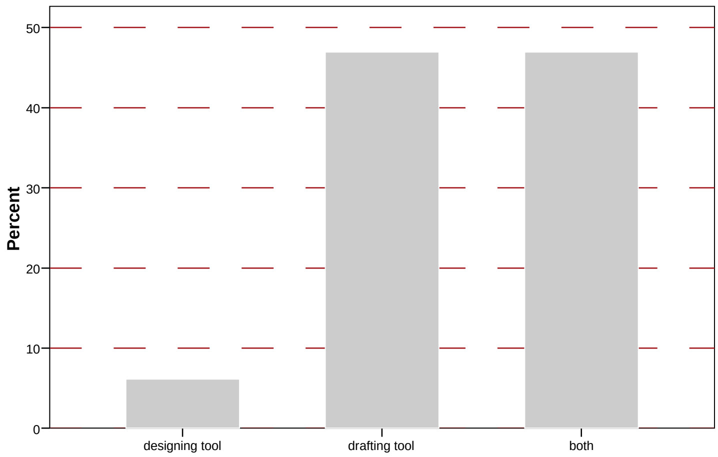


Figure 6-10 A bar chart of student's view of CAAD usage in term of designing and drafting

Defining CAAD as a drafting tool provides more certain implications for CAAD's utility than a designing tool, (it depends on students' exact meaning of designing). Although the ones who tend to use CAAD as a drafting and designing tool demonstrate either the dual meaning for both activities, or the dual purpose of using CAAD. Either way CAAD is considered mostly as a drafting tool.

6.2.4 CAAD Use in the Early Phases of Design

As shown in figure 6-11, the sample felt that using CAAD had proved to be helpful mostly in exploring complex geometry in design (70%). With an impact on straightening up pre-conceptual ideas (54%), identifying design problems (52%). Forty six percent of the sample also felt that CAAD affects understanding design and speeding up of the design process. While 44% felt that CAAD influenced communicating ideas to others, there was a lesser impact on aspects like thinking of other design variation (34%). They felt that it only had a minor impact on aspects like expressing the design ideas (28%) and understanding the design brief (16%).

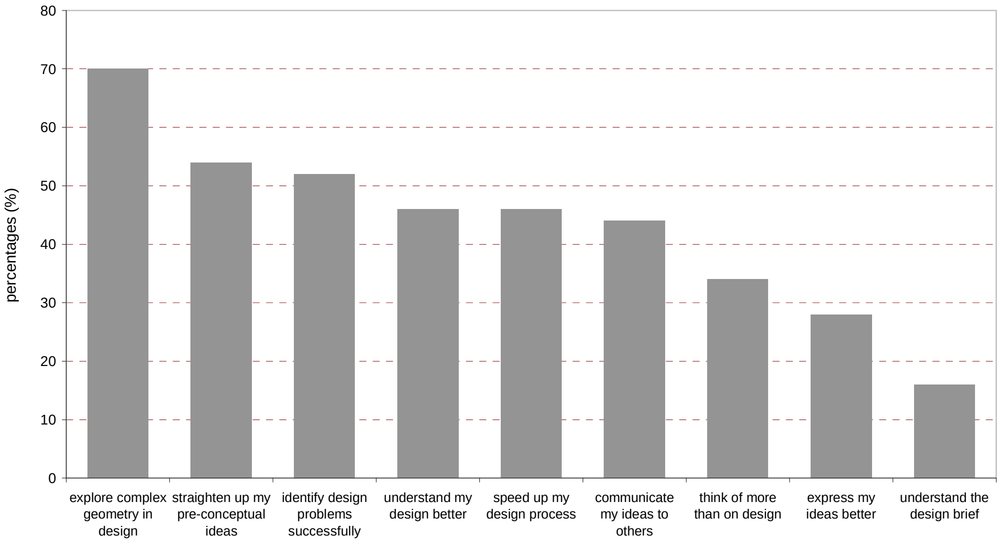


Figure 6-11 A bar chart of CAAD's positive impact

Only three students (6%) responded to why they thought working with CAAD had changed their opinion about CAAD's role in conceptual design. This change in opinion was positive when it was based on empowering the student "*to arrive at complicated form" and "giving more creative result."* Otherwise, the change was neutral in two instances: *"hand sketches show more direct thinking"* and "*I have always thought of CAAD as another tool to be used in connection with other techniques*." This suggests three points: (1) positive or neutral appraisal of CAAD would encourage the effective use of CAAD in conception (or at least CAAD exploration), (2) using CAAD actively in conceptual design may change the students' opinion about its role in conceptual design dependant on the reached result, and (3) introducing CAAD in conjunction with sketching and modelling is important to give some kind of critical appraisal for each.

The students reported what types of drawing they might use for CAAD. The types of drawings are shown in Figure 6-12. The drawing types varied from the most accurate orthogonal drawings of sections, elevations (17 statements) and plans (15 statements) or diagrams (26) passing by final (11) detailed (9) representations, 3D drawings (8) and perspectives (4) and ending with the most interesting type for this research, *conceptual* and *conceptual layout for sketching over*. The low frequencies for conceptual and layout drawing for tracing indicates that there is some kind of inclination to use CAAD for conceptual drawing or what students consider as conceptual.

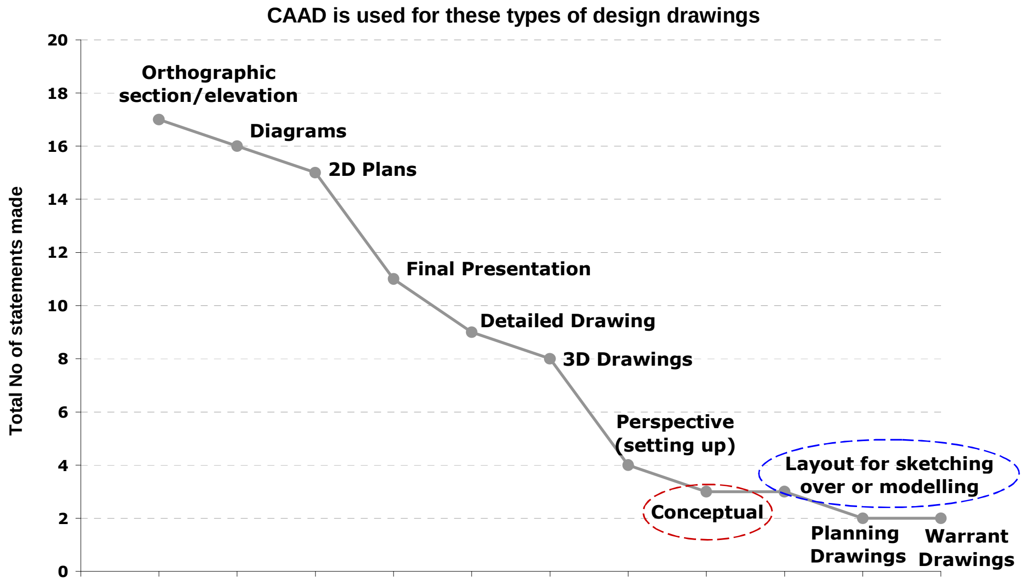


Figure 6-12 A line chart of CAAD drawing types

With respect to the reasons behind the samples tendency for not using CAAD for conceptual drawings, the sample statements were coded into: (1) CAAD restrict my thoughts (indirect way of thinking) as opposed to (2) using a pencil/hand (direct way of thinking), (3) time consuming (efficiency, complex), (4) drifted by CAAD parameters (computerised environment), and (5) the project type and size. Most of the statements (16) made were concerned with thought and thought development, CAAD was conceived as restricting both. (11) Using a pencil is a more direct way of thinking and is more spontaneous.

6.2.5 Design Media Preferences

The students were asked if the act of drawing is important to develop their ideas. Answers was measured on a five–level scale starting from completely agree (1) to completely disagree (5) and are shown in figure 6-13. Sixty-two percent of the sample completely agreed and twenty percent mostly agree. Sixteen percent of the sample neither agree or disagree.

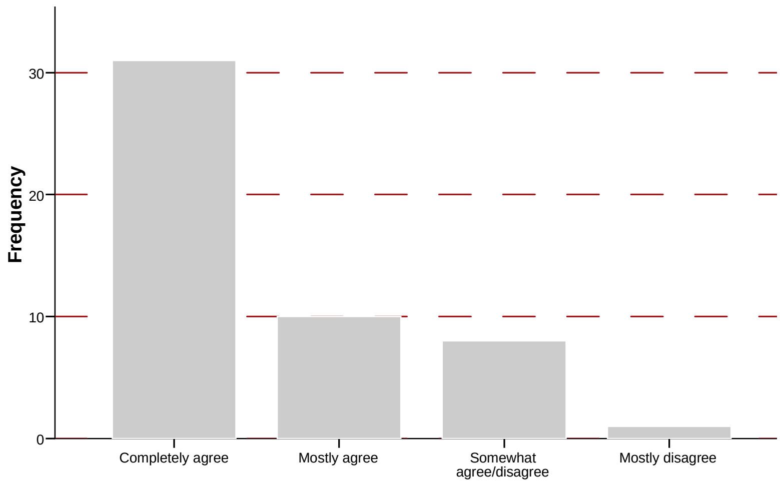


Figure 6-13 A bar chart of students' views on drawings importance

As well as 62% of the sample thinking that drawing on paper before starting CAAD is very important, another 26% considered it as important. Meanwhile 10% reported that this was not important for them.

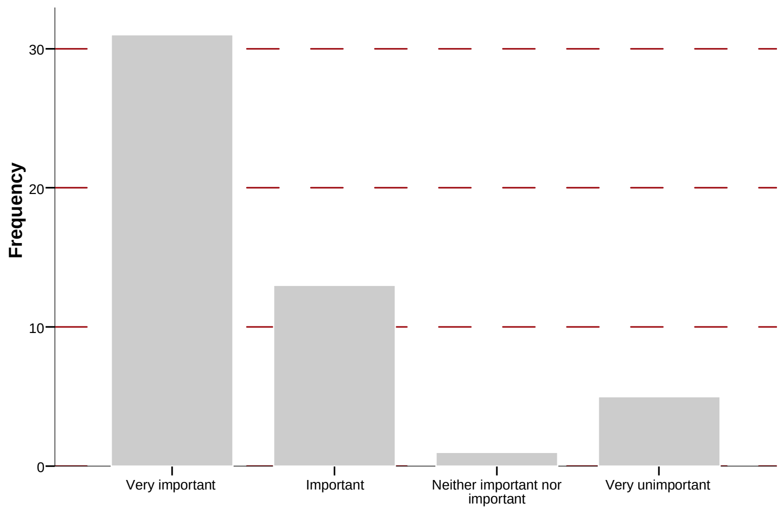


Figure 6-14 A bar chart of students' views on drawing on paper before starting CAAD

In answer to how often CAAD is used for creating 2D abstract drawings at any stage of the design process, the majority responded positively as demonstrated in figure 6-15. Most of the responses (54%) create 2D abstract drawing sometimes, 18% create them often, and 8% create them always. While 20% of the sample never create 2D abstract drawings, which means that CAAD is used mostly for final orthogonal drawings without the characteristic of abstraction (as shown in Figure 6- 15).

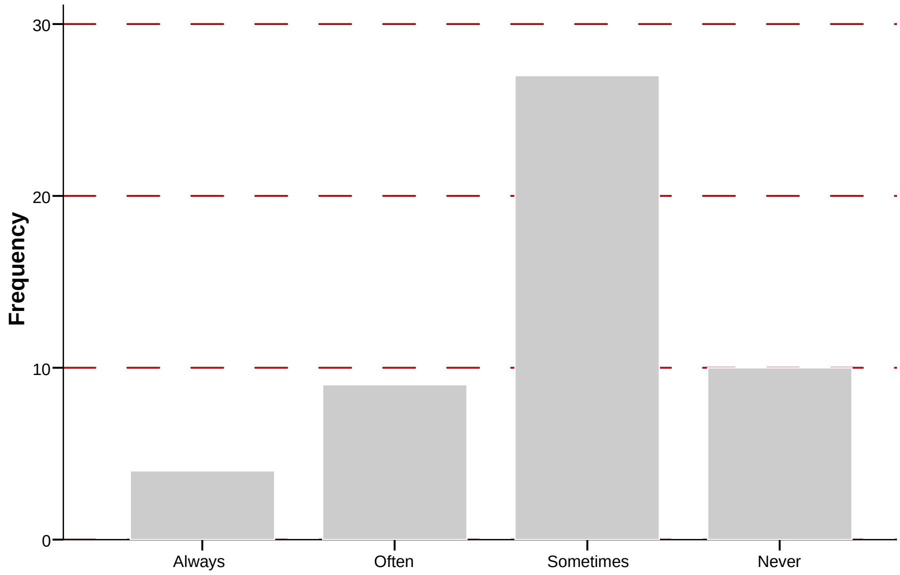


Figure 6-15 A bar chart of students' frequency of creating 2D abstract drawing

The majority of students indicated that they tend to shift from CAAD to any other medium(s). The prevailing trend among the sample, 60%, was the transition from CAAD to other mediums such as sketching or modelling. Another trend was the transition from CAAD to a specific medium, i.e. 30% of the sample indicated they needed to switch from CAAD to Sketch. At the same time, only 4% of the sample tended to shift from CAAD to physical modelling. With a remarkably low percentage of students (4%) who felt that they did not need to change the medium.

Designers tend to change the conceptual medium to obtain various insights into the solved problem or the developed design, and taking this into consideration suggests that this also applicable to CAAD. However, if constant engagement with one medium could lead to fixation early in the process, this implies a negative impact of CAAD on thinking or creativity. The low percentage who felt that they did not need to shift from CAAD are competent in using CAAD, and therefore they do not feel restricted.

The students identified the changes they thought that CAAD had an impact on. Most of the students agreed that using CAAD early in the design process affected their sketching tendency as the students were likely to sketch less.

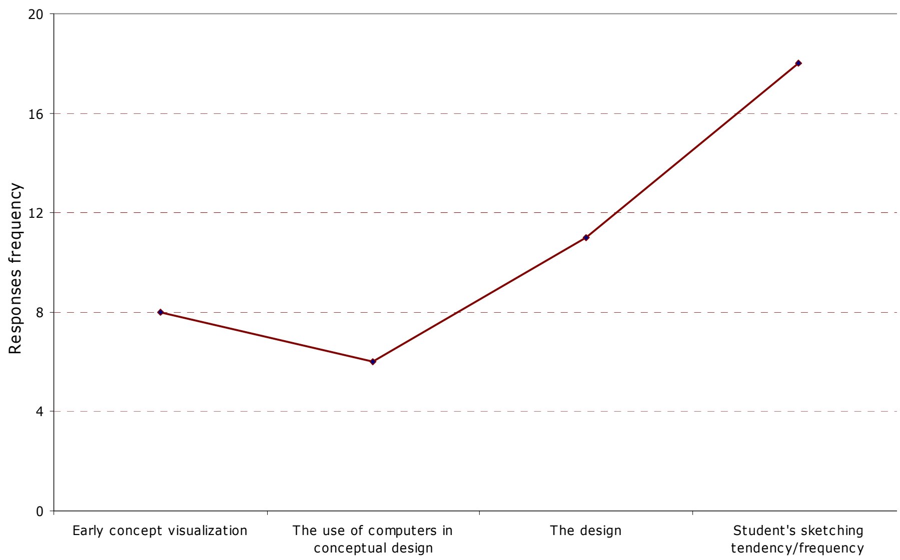


Figure 6-16 A line chart of the impact of using CAAD regularly

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 changed their sketching tendency, with (64%) stating they tended to sketch less.

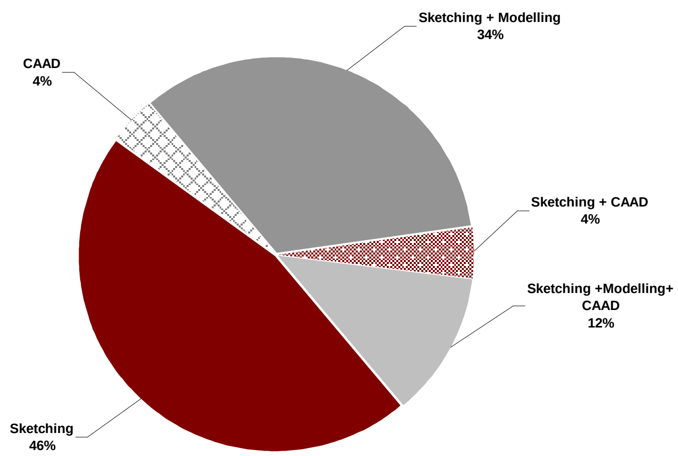


Figure 6-17 A pie chart of the easiest media to develop ideas

With respect to conceptual medium preference, the highest percentage of the sample (46%) reported sketching as their preference, while only 4% reported CAAD. The rest of the sample specified other medium besides sketching, i.e. sketching and physical modelling were reported by 34% as equally easy, whilst sketching and CAAD were reported equally by 4% only. Twelve percent reported that sketching, physical modelling and CAAD are equally easy to develop new ideas suggesting that a combination of media is preferred.

More than half of the students (54%) reported that while working with CAAD they found themselves thinking mainly of the drawing appearance, details and finishes, whereas 24% of the students reported that they do focus on the conceptual content of their design. Others (12 %) reported that they are able to manage both: conceptual and non-conceptual issues.

In addition, the students were asked about time spent on what they had drawn on screen, or on how to draw it, or both. More than half of the students (54%) answered that they spent most of the time thinking or considering both: what to draw and how to draw it, however, 34% spent the time on what to draw on the screen rather than thinking of how to draw It. While 6% of the sample could not decide on which aspect they spent their time.

Finally, with respect to CAAD as a medium, the majority (74%) reported that within CAAD they find it easy to follow their thought sequence. While others (24%) reported that within CAAD it is harder to follow their thoughts. When it is easy to develop ideas using CAAD then CAAD has no effect on the flow of thoughts as opposed to when others felt it harder to follow their thoughts. This point is interesting to explore further through design protocol study.

6.2.6 3D modelling at the early phase of design

The responses of students to whether they are experimenting with 3D concepts while using any CAAD program are shown in figure 6-18. Nearly quarter (24%) of the sample only found it interesting to see their early concepts in CAAD. Fourteen percent of the sample also felt positive about using CAAD early in developing many ideas and (18%) in offering unpredictable results for their design pre-concepts. However, a similar percentage (24%) of the sample felt negative about exploring their concepts early in CAAD, 8% reported that using CAAD early is waste of time, while 12% would have to obtain a higher level of CAAD practice or experience before exploring their concepts in CAAD.

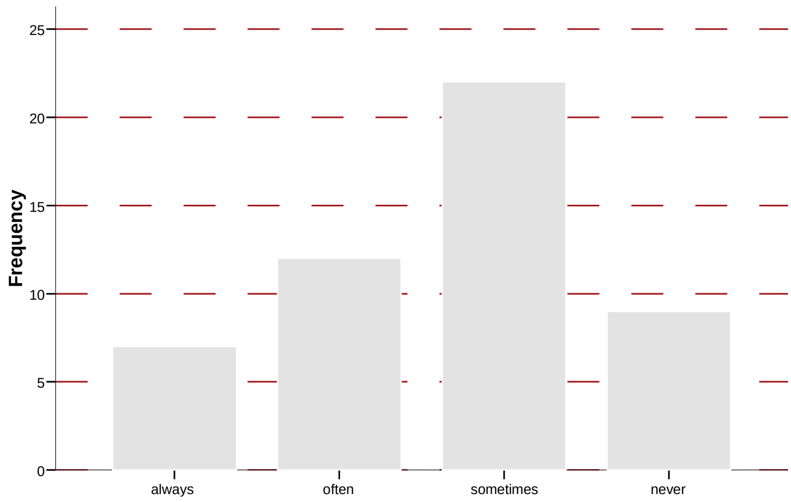


Figure 6-18 A bar chart of the frequency of creating 3D models

With respect to the early phases of the design process, as shown in figure 6-19, the students responses varied in relation to which conceptual phase (design brief analysis, outline design, final sketch design) they would create a 3D “digital model.” More than half of the students (58%) would create a 3D digital model at one single phase rather than creating a 3D digital model at all phases (20%). While 16% reported that they would not create a 3D digital model at any of the early phases of design concept.

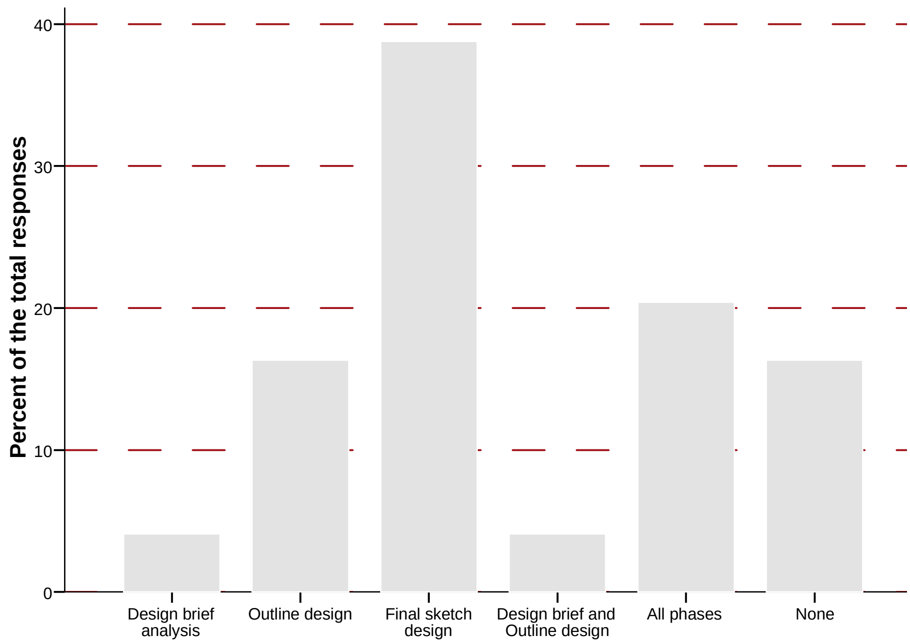


Figure 6-19 A bar chart of 3D digital models and design process phases.

The responses within any single phase were hierarchical. The highest percentage of responses (38%) specified the latter phase of final sketch design, then the outline design phase (16%), and finally the earlier phase of design brief analysis with the lowest percentage of responses (4%). However, two instances (4%) reported that they would create 3D models at the two early phases of design; brief analysis and outline design. The hierarchy of the responses is interesting as it shows that the CAAD digital model is always evident during the latter phases rather than the earlier phases of design conception.

Moreover, exploring their work in 3D in either mode (physical or digital) affects the students' work in different areas. They mostly ticked the following statements (effects): "*make it easier to imagine spaces*", "*it is good for presenting. Showing perspectives of the spaces in the building.*" and " *helps visualisation of form and spaces".* The following effects came second *" it allows seeing in a way I can't in 2D.*" and " *it gives me a better understanding of how the ideas would function*." Fewer students ticked that a 3D mode of work would affect the students work *"it provides me with a more realistic approach",* and " *it helps visualisation, but also can be a time wasting diversion."* This is shown in Figure 6-20.

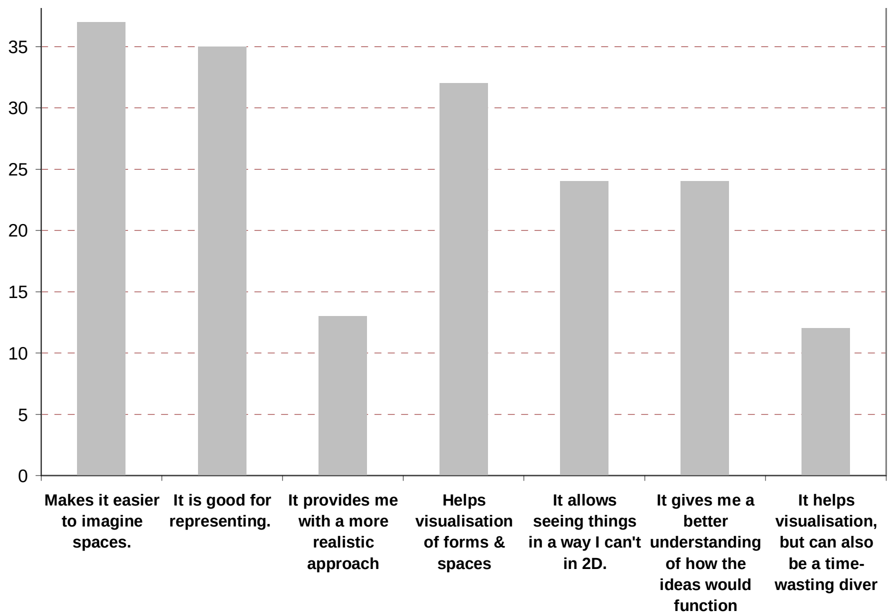


Figure 6-20 A bar chart of students' views on exploring ideas in 3D.

The students rated the benefits of model making (digital or physical) in respect to eight criteria. The responses are shown in Figure 6-21. Compared to digital modelling, physical modelling was ranked higher in achieving all the intended criteria, apart from speed of completion in which digital modelling is the most convenient. Otherwise, digital modelling always scored less than physical modelling.

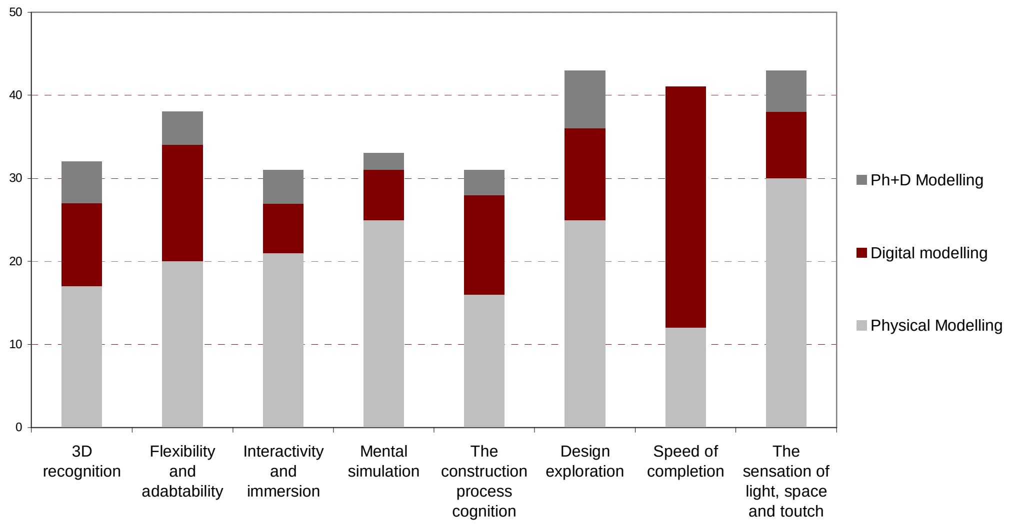


Figure 6-21 A bar chart of modelling types and usefulness

6.2.7 CAAD Teaching Methods

Most of the respondent group (66%) considered learning CAAD within an architectural practice to be 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 students felt the rational-practical association between CAAD and design. Thus, architectural practices provide a supportive environment for learning CAAD.

Finally, students were asked about what topics they would like to see covered in another CAAD course. The statements were coded under three main categories: 1) better CAAD teaching methods, 2) 3D focused practice and exercise, and 3) further design analyses (temperature and lighting). Among the statements made, the sample reflected upon the term course and its relation to university teaching. These courses were described as “confusing” and “poor” which affected CAAD learning. Some of the students referred back to their high school teaching as the last CAAD courses they had. Another point made was that earlier teaching would be more helpful especially in 3D and other technical issues like integration and compatibility between the different packages.

6.3 Summary

The results have provided this research with an accurate description of a modern perspective of CAAD as part of digital technology. It was also the earliest engagement with the sample (final year students) and the wider base of responses to characterise students' experiences that had preceded this stage of education.

The sample mean age was 23.8 years (more male students than female by 8%) although the age range was high within the same stage. Access to digital technology, laptop, Internet connection and CAAD was higher compared to a personal computer; indicating that the sample had access to digital technology materials.

The sample was extremely consistent in assessing their architectural design skill and extremely inconsistent in assessing their sketching and CAAD skills (range is high) by scoring various levels of sketching and CAAD experience within the same sample. However, CAAD skill range was higher (good-very good) than sketching (fair- good) to suggest two things; firstly that students were more confident about their CAAD skill than their sketching skill and secondly that there are various levels of confidence in using drawing skills in general and CAAD in particular within the same stage.

"Personal effort" and "architectural practice" successively were ranked as the main sources for the sample's CAAD experiences rather than from university courses. From their perspective, on average the sample had learned CAAD 4-6 years before the study and used CAAD within the past 2-4 years. However, most of the students learned and stated using CAAD at the same time. The sample identified architectural practice once again as the most useful way to learn CAAD as a designing tool and the students were lacking a systematic way of using CAAD in design methodology.

The sample's CAAD experience affected their design capability but has not improved their architectural design skills. The majority were positive about the generation of conceptual design using CAAD (Figure 6.6). They also use CAAD regularly in both phases of the design (early and final) but rarely use CAAD only at the early phases. CAAD is defined primarily as a drafting tool or a tool for drafting and designing. This suggests that there are signs of change in the relationship between CAAD and concept design on the levels of usage, preconceptions and phases.

The sample used the following CAAD software programs (professional systems) successively: AutoCAD, SketchUp, ArchiCAD and 3ds Max. Using CAAD exclusively in any phase of the design process was only acknowledged for the final sketch design phase. However, the use of CAAD exclusively was negatively appraised taking into consideration the range of tools and mediums for early design. Therefore, a combination of tools and mediums are the prevalent trend of design media engagement.

The sample felt that using CAAD in the early phases of design proved to be most useful for exploring complex geometry in design, straightening up pre-conceptual ideas, identifying problems, speeding up the design process and communication. Moreover, CAAD was used for a variety of drawings but mostly for 2D orthographic drawings, plans and diagrams, followed by final presentation, detailed drawings and 3D drawings, and conceptual drawings were reported last. This suggests another change in the relationship between CAAD and conceptual design but on the level of drawing types.

Alongside the digital appraisal of the sample's skill and motivation, the sample strongly agreed that drawing is very important although they sometimes do 2D abstract drawings in CAAD. They must start with paper sketching before moving to CAAD, and while working with CAAD they tend to switch from CAAD to sketch on paper. Thus the sample's design practices are engaged in a sequenced medium of sketch, CAAD and sketch, which is rooted in the traditional methods of drawing and sketching. However, CAAD practices have influenced their sketching tendency in fewer instances, as sketching is still found by the sample as the easiest medium for developing ideas.

The students agreed that using CAAD had influenced and changed some of the traditional practices. Most of the students agreed that using CAAD early in the design process had affected their sketching tendency as they tended to sketch less. CAAD became a changing factor in the following facets of the conceptual design phase. The least changed facet was the application of computer in conceptual design and the most frequently changed facet was the sketching tendency.

While working with CAAD the sample noticed that they do tend to work on the drawing appearance, details and finishes rather than the actual content of a drawing, whilst at the same time trying to balance between what they are drawing and how to draw it. Therefore, CAAD also became a factor in shifting students' attention from design to design presentation and from design to CAAD operations.

Describing the sample in terms of 3D (traditional/digital) practices, the participants agreed that exploring their design early in 3D is interesting for idea development, variation and unpredicted results. They sometimes tend to create 3D CAAD models at any phase. It is likely, however, that they would create a CAAD model for the final sketch design and outline design successively. They find that creating 3D models affects their work in imagining spaces, representation and perspective, and forms visualisation. However, the only advancement in digital models was the speed of completion.

The results in general show that there are two patterns of developing ideas with respect to the medium. In the first pattern, only one medium is used for external ideas development and sketching is still leading this interaction. However, using CAAD solely for external idea development was ranked by only two students as being easy to develop ideas. Although the rate is low, this could imply a changing trend towards how CAAD is viewed in the conceptual design phase, a transition toward accepting CAAD. The second pattern was medium variation, i.e. using another external medium beside the leading one as a complementary process; the prevalent preference was sketching and modelling rather than sketching and CAAD. In the following two chapters (7 and 8) these issues are further investigated on a deeper level of inquiry within the studio social context of final year students and project model, to improve our understanding of the role of CAAD programs in the traditional design studio.

7 Study Two: Studio Reflection

This chapter presents the findings of the studio reflection study (stage two of the case study). The first section introduces the study in terms of its purpose, objectives, analytical framework, and cases description. The findings are then presented in three sections according to the points of reflection that were framed by the project model. The second section presents the analysis of the students' reflection in the first phase of project work. The third section presents the analysis of the students' reflection in the second phase of project work, and the final phase reflection is presented in the fourth section.

7.1 Introduction

With regard to the survey presented in Chapter 6, the purpose of this study was to empirically corroborate some of the theoretical aspects of the survey to move beyond students' theoretical assertions, since these were not supported by evidence (e.g. visuals or design solving context) or other cues. Testing these assumptions within its evolving (learning) context would enrich the survey's results. Hence, making an inquiry within the context in which their knowing-in-action (Schön 1983) is operating, would provide a better understanding of how students' cognitive differences (i.e. in terms of sketching, computer literacy and CAAD skills) are balanced and used in real context. As shown in Figure 7-1. The studio-based project is a learning experience in the first place: through design engagement, students gain new knowledge and skills (abilities). Moon (2004) sets the limits of learning as "*knowing that*" and "*knowing how*", and the Project Model provides the means and context for learning to take place. That is, "*knowing how*" to design occurs through engaging in a process, i.e. applying various design methodologies within the boundary of a design problem; "*knowing that*" occurs when knowledge about concepts and design situations is revealed, through the act of designing (Smith, Hedley and Molloy 2009; Schön 1987).

This study's methodology resembles Schön's model of "*reflection-on-action*" and Reymen's (2001) "*structured reflection"* methodology. The purpose of the case study was to observe CAAD utility as a design tool in the context of the studio (cohort 06-07). This was recognised through the interaction between students, tools and their reflection on why they have used a certain tool for task A or B. The targeted sample reflects a cross-section of final year architecture students, where they have been educated and encouraged to use CAAD at the latter stages of the design process.

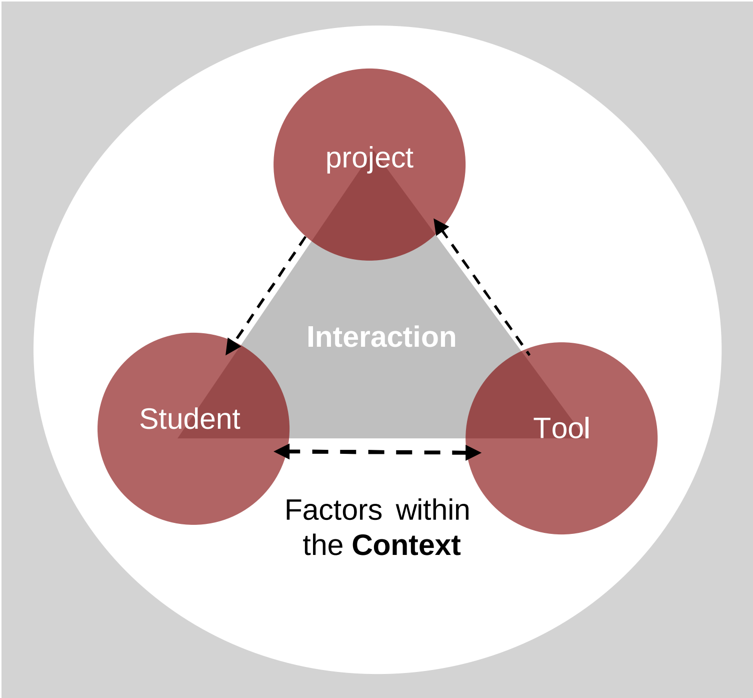


Figure 7-1 The interaction among student (person), tool, and project brief in a the studio context.

The studio dynamics are understood as a context of learning (group work, reviews, tutors and pin-up), and the project-based approach of the final year should include the identified characteristics of final-year students.

As was mentioned previously, in section 5.4, the reflection study is the second stage of the case study which consists of three points of reflection as shown in figure 7.2.

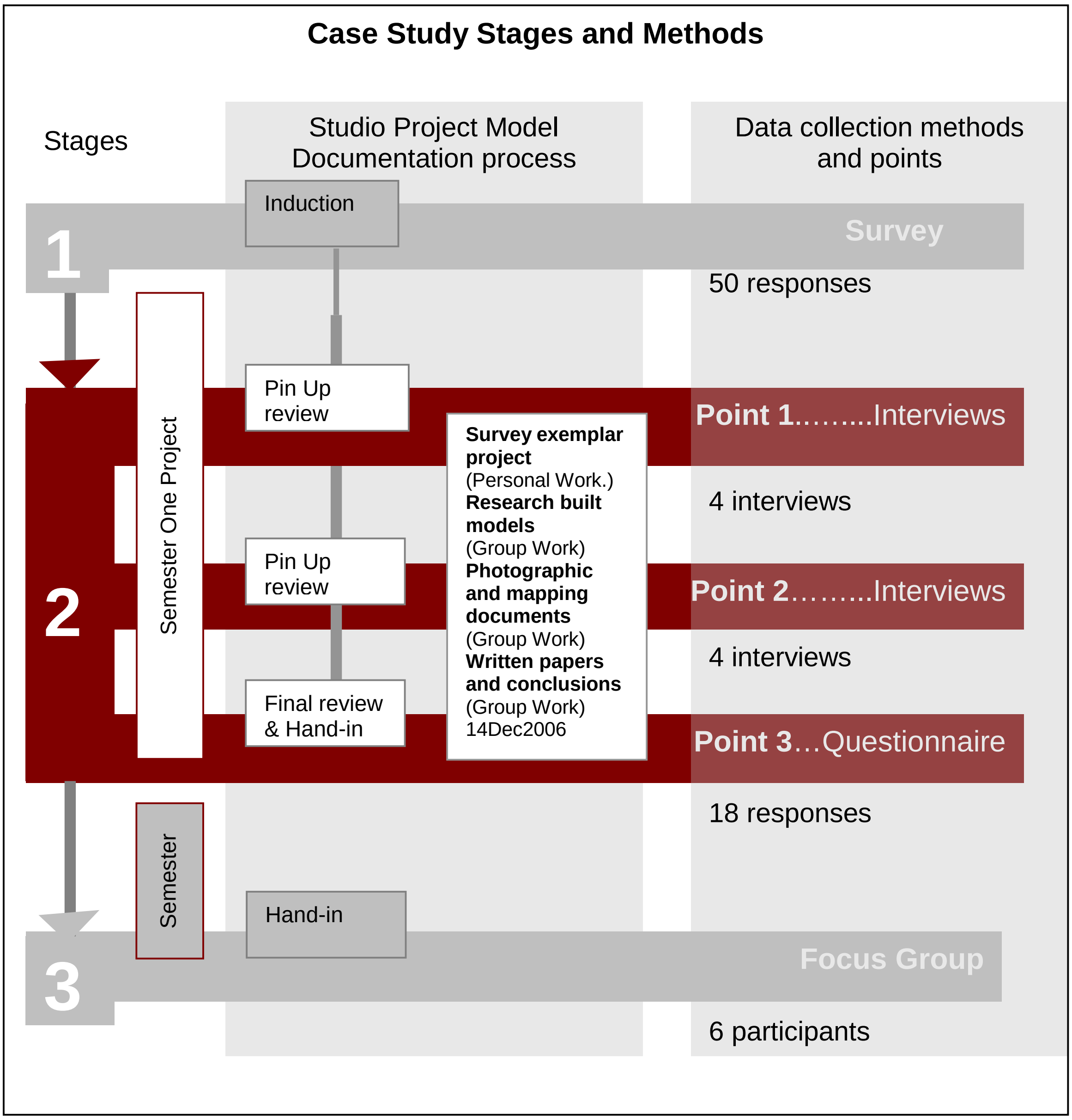


Figure 7-2 The case study stages and this chapter structure in relation to the project model and point of reflection.

7.1.1 Case study description

At the time of conducting this study, MArch studio (cohort 2006-2007) embraced a relatively new studio-based project in term of its objectives and its investigative process (the students were asked to form theoretical themes from the suggested precedents to be used in the development of design layouts). It took a holistic approach, starting with the precedents as a (teaching) case study for each given project (five projects in total) and continuing into a more focused level of abstraction. The studio encouraged collaborative work: students worked in groups in the initial phase of understanding precedent contexts and layout development.

The MArch studio was mainly equipped with drawing tables and computers (6 Desktop computers for the cohort - 50 students). Students' range of media should be elective to encourage media exploration; however, it was restricted by the small number of computers at the studio. Otherwise, they could use computers away (detached manner) from the studio context in a lab on the same floor or other floors.

7.1.2 Analysis

This analysis focuses on categorising the features of students' reflection on the project model (projects, approach, means and tools). This categorisation was based on the methodological *interest in meaning, perspectives and understanding* (Woods 2006 p.2).

Although questions were asked in the same sequence, there were many shifts based on the student's immediate reflection. These shifts were related to the student's design situation as an individual case. Moreover, there were many overlaps in the answers pertaining to the same meaning or theme. The generated data were based on four sets of questions, (these are provided in Appendix C: 1, 2, 3 and 4).

The students recruited at every point of reflection presented a subgroup of the Master of Architecture cohort (2006-2007). This cohort had completed the questionnaire survey at a previous stage in the study. This is shown in Figure 7-2.

As previously mentioned in section 5.4, this study was structured around the first semester project three submissions (pin-ups), hence three points for reflection. Four valid interviews were selected from the first point of reflection, and four further interviews from the second point of reflection. These two points' emergent themes were subsequently triangulated at the third point of reflection with 18 questionnaire responses. The selected cases are described and summarised in Table 7-1.

Table 7-1 the case study used mixed methods of studio reflection.

Points of Reflection	Project structure	Methods	No. of Cases	Gender	Mean Age	section
point one	Semester one, after the main course work at three critical events of studio reviews	Semi - structured questions set 1.	Sa1 Sa2 Sa3 Sa4	male female female female	23	Sec. 7.2
point two		Semi structured questions set 2.	Sb1 Sb2 Sb3 Sb4	female male male male	23	Sec. 7.3
point three		Questions set 3.	18 Sc responses	11 female + 7 male	23	Sec. 7.4

The key findings are presented in separate themes, although they overlap and interact with each other. These themes are key to understanding the present role of computer aided architectural design (CAAD) in the studio context. It is hoped that such findings (discussion) will initiate a change in perspective and help architectural education to determine the next steps and CAAD's future role.

The phases and progress of studio work are important to this research, and are distinct at each point of reflection. Every phase has raised topics that were developed through a process of data analysis. Within each phase, topics were identified under four main categories: project model, stage representations, design process and skills or preferences.

The analysis of each point of students' reflection is presented and summarised in three subsequent sections: 7.2, 7.3 and 7.4. The emergent themes are then discussed in relation to the focus group's findings in chapter 8.

7.2 First Point of Reflection

The first point of reflection was at the beginning of the studio design process in which the students described their work (practice) as part of the project model. At the beginning of the studio project, students had to consider the proposed precedents for their project type. This would enable them to identify a number of themes on which to base their conceptual propositions for the design of a new site. All the interviewed students were working on a master plan of a new town.

The analysis of the first phase data consists of four students: one male (Sa1) and three female students (Sa2, Sa3 and Sa4). A general description is presented in table 7-2. The second set of questions (set 1), in Appendix C-1, p. 360, was employed.

Table 7-2 The recruited cases and work description

Cases	Work Description
Sa1_M student	Worked on the precedent study using CAAD 2D drawings, and suggested another media (filming the precedent) to express what he deemed to be important.
Sa2_F student	Worked on the precedent study by making a physical model.
Sa3_F student	Worked on the new site model, and presented in 2D CAAD drawings.
Sa4_F student	Worked on the new site model, and decided to create a digital model first to provide a CAAD based template for the new site physical model.

The following sections present the categorised features of students' emerged reflection.

7.2.1 Project model

The purpose and role of CAAD has been analysed in relation to students' intent within the context of this year's project model. The purpose was to identify whether CAAD is recognised as part of the project model or not.

At the beginning of the project, students' description of project work was important to reveal their objectives in using a certain tool (or CAAD) in design problem identification (snippet of the whole process). For example, student (Sa1) summarised what he had done (as part of the group) by highlighting two aims: looking at the precedent in terms of *what is there* (precedent analysis by coding building types and uses) and "*how to show* the required information" (Sa1). This shows how informational content (conceptual) is interlinked and related to how it is represented (presentational), to convey a conceptual intention or understanding. There is no division between the two, as they are parallel to each other in the student's line of thought. The conceptual theme of town development had framed the aims, which were "*based on when they were built*" (Sa1).

In general, there were three main themes: conceptual theme "*tried to work out the various zones of things (buildings, what type, parks, etc.) when they were built.",* practical theme *"work out a way of showing this in*.." and technical theme *" then actually do it as well .."* (Sa1).

Simultaneously, in the case of Sa2, she seemed guided by the practicality of the task or "*job*" of making a physical model as part of the precedent study:

> *"Our job (at) the first stage was to get all the levels for making the model, cutting out the bits and putting it all together."* (Sa2).

As opposed to Sa1, the direct connection between the methods and the explored medium is somehow missing, and one reason for that could be the choice of medium, which had been set by the project model (tutors) in terms of both scale and material, which will be discussed later.

In the case of Sa3, project work was described by another feature of the student's perspective, the holistic approach of collecting material and then "*sorting through the materials".* (Sa3). Gradually the student defined her role within that contextual work by stating that:

> *"I was in the mapping group so I got to research quite a lot about the town; I enjoyed that, the analytical part."* (Sa3).

This extract reveals three different aspects of the studio work. The first is the application of similar analytical methods (coding, mapping) that were used in sorting the gathered material. Secondly, it provides an example of a positive stance (enjoyment) towards the relatively new design approach. Thirdly, compared to Sa1 and Sa2, it gives an indication that not all students were progressing at the same pace. Following this, Sa3 summarised what she had done (as part of the group) by recording two acts:

> *"I have gathered my material, but it is just looking at what is there and what will come basically and what I can learn from that."* (Sa3).

One act refers to gathering materials of "knowing that", and the other pertains to "knowing how" by the analysis of the gathered material, which is referred to as "*Housing layouts.*" (Sa3). Similarly, student Sa4 described this stage of work by highlighting a similar meaning in research, which was one of the thematic notions of the project model:

> *"Looking for information, so that we can use it and where to find it."* (Sa4).

This search for information was required to enable the delivery of two of the project-required products: precedents analyses and precedents physical models.

To summarise, the MArch project model was a typical example of the problem identification phase of the design process. Moreover, these responses have demonstrated that student learning (knowing-in-action) varies from one student to another, although they are considering the same design problem (project) and project phase. Whether using similar or different methodologies, group work has assigned different tasks with different levels of engagement. The studio model and approach had been reflected in the meaning of the words used by the students, such as *information*, *gathering material* and *sorting*, therefore, even the terminology used by the project model can be traced in the students' reflection. There was no role for CAAD methods under this category as CAAD was not an explicit part of the project model.

7.2.2 Representations

Representations had connections with the analytical methods and tools used. Students labelled the method of documenting as "filming" due to the analytical methods of coding and its relation to the medium used.

> *"Then we went to Stonehaven and made the film and sort of an extra thing to show".* (Sa1).

Building on, "*working on a way of showing this in*," the Sa1 extract shows a direct connection between the method used to convey the new place experience and the analytical methods that were used to study the precedent (and to understand it architecturally). Based on when it was built, this extract indicates that the *methods* used by the students are adequate in establishing such conceptual relations. Moreover, they are related directly to the medium (filming) used to convey the experience felt and its conceptual structure:

> *"I tried to film it in a way so that we started in the oldest part and worked away through the different areas based on when they were built. So instead of just picking a random route we went from the oldest and tried to end up in the newest"* (Sa1).

Although photography has been one method of documenting and referencing architectural visual material, some would argue it is static. Dynamic video recording brought other dimensions to that process: time, progress and change.

Another example was student Sa2 who was engaged in physical modelling. Later in the interview, she justified the benefits of what she had been doing for the last two weeks (time consuming).The conceptual implications were identified as:

> *"It might have an influence thinking about the public space and private space and working on the model may be have to show buildings and places behind them, that was actually more interesting part of the building what's behind the main façade that people don't see."* (Sa2).

In general, this extract shows a seemingly direct relationship between the explored medium of the precedent and the student's conceptual theme which had been identified. As she worked within a 3D (physical) medium, the conceptual theme was in relation to the massing, i.e. the relationship between void and solid. Although, the practicality of the task had been emphasised first, implicitly it had guided some conceptual themes that enabled the student to focus on one problem of urban design. The other two cases participants were from the drafting group, therefore, they were mainly documenting the precedent study and analyses.

To summarise, the representations used were of typical connection to the role that was set as part of the group work and problem identification phase. Moreover, these responses have demonstrated that student learning (knowing-in-action) took place within a design situation, thus the conceptual themes vary from one student to another, although they are considering the same design task (project) and especially, when different methodologies are used, a variety of representations led to alternative ways of thinking. Most of the interviewed students were engaged in drawing, however, physical modelling was another media that had been described as time consuming because understanding develops through practical engagement and after the model is finished. Moreover, using new representation media was also observed, e.g. filming, and was welcomed in the studio context by tutors. CAAD's role in this category was to document and present the analytical studies, which resemble the role that was initiated at the induction of the warm-up project. This indicates that the methods learned in the studio context are favoured and practiced.

7.2.3 Design process

Although the project model had framed most of the design methodologies that were regarded as traditional, the same learning context had brought certain CAAD practices to the process. In this context, these practices acted as an intervention to speed up the design process.

Alongside the emergent themes, time was mentioned implicitly or explicitly as an influencing factor. The amount of time spent would affect student's sense of fulfilment. Thus, students resorted to CAAD for speed in drawing, modifying and modelling as CAAD had been described as the "*quickest way*" of doing and completing tasks. Another instance was the project "*time schedules*".

> *"Well the CAAD was used because it was the quickest way of doing it, I think some of the other plans that other people did they took into Photoshop but for me I just did it purely in CAAD."* (Sa1).

> *"Yeah, CAAD was used because cannot draw it by hand. It is all probably related to time schedules."* (Sa4).

CAAD also played an important part in speeding up the process of making the physical model of the new site. Student Sa4 felt that CAAD modelling was necessary for the making of the physical model, by providing a template (technical drawings) for how to make the model. The 3D digital model acted as a sub-process within a process. This sub-process was devised by the students themselves "*We also did a 3D (site) model just for our own purposes*." to fulfil one of the project model requirements. e.g. aiding physical modelling by digital modelling to manage its complexity and size. This is shown in Figure 7-3.

> *"We did for the big model. We did a contour map, and entered it into*

SketchUp, a 3D render of the site, so we have got a skin of the site and from that we just cut the sections off and pushed them out so it was just a process really." (Sa4).

In general, the focus was on one theme: a practical theme, by which the student gained CAAD skills, allowing the use of the given information to create templates of the physical model.

2D map

Survey and levels coding

3D (CAAD) digital model

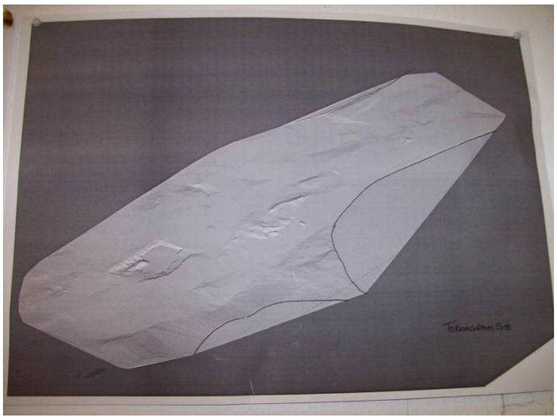


Figure 7-3 a digital model was created to prepare templates for the making of the physical model.

These responses overlapped with another question about the kind of design problem that the student had worked on, which evoked a non-conceptual design issue (problem). Time was identified as the only restriction, quoting student Sa1 *“the length of time that we had to try and collate such a huge map*”(Sa1). The student felt that the time required for their part of the study was a problem that they had to deal with at an early stage; describing the produced map as “huge”. The process of understanding and identification needs more time *“I suppose the time restraint was probably the biggest issue in trying to get everything sorted in the way that we wanted it to be done, during the time, that was the main one.”* This identified issue is directly related to the group analytical strategy of the precedent and how to present what they found and what they want to emphasis, i.e. moving from the atomistic (analysis) approach to the holistic (representation) approach.

In brief, these extracts refer to students’ awareness of time as an important constraint that affects their actions and how much work they can do. Therefore, time influences students’ sense of achievement, hence CAAD’s utility. Under this category, CAAD had an active role in speeding up the process.

7.2.4 Design tools

With respect to the interaction between students and workplace tools within the context of the project model, two types of interaction with studio design tools were identified. The first type, a compulsory interaction was required as part of the project model (tutors directed), which was dominant in the problem identification stage. Quoting student Sa2 who worked on the precedent models, she said:

> *“Because we were given it (referring to physical modelling requisite)” and* “*The model, it's been quite extensive by the tutor*” (Sa2).

Moreover, the second type was an elective interaction with design tools whereby a student decides to use a certain tool or medium that is framed by the student’s needs rather than requested by the project model. This was observed frequently, where students who used design media other than physical modelling to reflect on their personal methods and preferences. Quoting Sa3:

> *“We were not told what sort of [media] to use so we just used them because that was what we use.”* (Sa3).

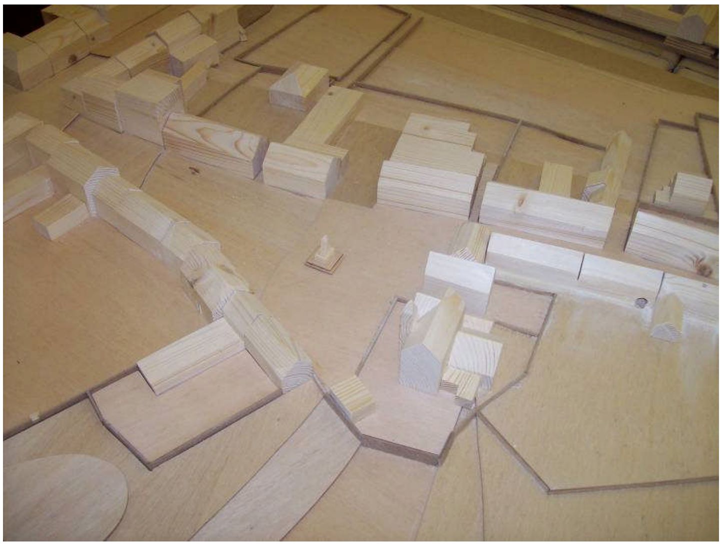
A similar example from an Sa4 student extract states "*(students) were not really told what to do, we (students) were told what to look at, and then we explored it from there.*" (Sa4). This example provides another criterion for students' elective interaction, that is project oriented but explored differently. Table 7-3, shows the reported variety of media.

Table 7-3 Media used at the first point of reflection.

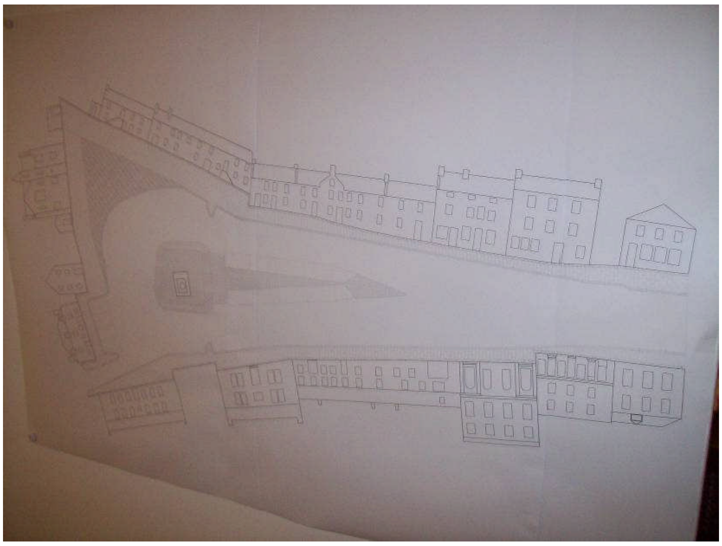
Media	Sa1	Sa2	Sa3	Sa4
Hand Drawing		+	+	+
Note Sketch			+	+
Scanned Drawings		+	+	
CAAD Drawing	+		+	+
Physical Model		+		
Digital Model	+			+
Site visit	+			
Booklet/images	+	+	+	+
Film	+			

This data raised a question; would each type of interaction influence the student's ability to assess and evaluate a tools appropriateness within the context of design problem identification and solving?

Each media, whether assigned by the project model or elected by the students, was useful for the same situation (design task) in understanding the issues that were related to the new design project. However, students varied in their perspectives on how the media they used had influenced understanding, hence problem identification. One example of this was physical modelling of the precedent and the new site.



3D physical modelling



2D CAAD Drawing

Figure 7-4 The precedent study consisted of 2D CAAD drawings and 3D physical models.

With respect to the usefulness of the physical models created, the second student (Sa2) who worked on modelling the precedent felt that modelling the precedent physically was important for her to understand the layout without drawing it. However, the prevalent perspective was against modelling the precedents for two reasons: it was not part of the design situation and was time consuming.

Student Sa1 pointed out that making a physical model is useful when the built model is the actual design project, not the precedent. Modelling the precedent when the design project is not part of it, was not considered useful. He stated *"I think in this particular case (their project), no, but in other cases it can be*." By "*other cases*," he meant that if the designed project is part of the precedent or part of the existing building, then it is useful to model it physically. That is, the studied case is part of the design situation "*in other groups they probably are (useful) because they're actually modelling the places they will be designing for"* (Sa3) then it is constructive because it is directly related to concept design (e.g. art school extension). Normally, precedent studies include visual 2D representations of 2D and 3D objects rather than 3D physical models (Schenk 1991). Moreover, Sa3 also had a similar perspective on modelling the studied precedent *"In this particular project I would say no, because the models were worked on at the same time as we were working on the drawings",* therefore, it was not seen as a constructive process.

However, this changed when the modelled site is typographical and blank, quoting Sa1 *"I think the Tornagrain model, the big model will be very useful, but in the next few weeks"* (Sa1). Student Sa4 claimed that *"probably would not have done it, or not two."* Model making was described as "*a bit too much work for nothing, for not enough gaining out of it.*" (Sa4). Moreover, she described the interplay between modelling the precedent and the new site at the same time as unhelpful for relating or transferring what is learnt from the precedent study to the new site, quoting Sa4:

> *"But when you build a model or you are building a house you are thinking about how you build that house. You are not thinking about what you are designing on another site in another week or two weeks of what is going to be."* (Sa4).

This extract reflects two aspects of the given project: one pertains to model making as practical in which technical engagements of "how" to make a model are emphasised instead of concentrating on what is to be modelled. The second pertains to the separate conceptual status of the student's two tasks (actions): studying the precedent and designing the project. Consequently, the new site model was considered necessary under one condition: designing with the modelled site or building.

Alongside the aforementioned reasons, the "big model" acted as a substitute to visiting the site, even if temporarily, i.e. taking place before the actual site visit. Quoting Sa1: *"I haven't actually seen that yet but I think both of them are useful, I think to actually see it laid out in front of you is far more interesting".* Before gaining the full experience of the proposed site, a 3D physical model was useful to give an adequate understanding of the actual site. Quoting Sa1:

> *"So I think to see the contours and the landscape and how there is a quarry in the middle, so you can see where that is, how it works and to see the actual place in 3D, I think will be very useful."* (Sa1)

Another perspective was provided on modelling the new site in two formats (digital and physical) which are both shown in Figure 7-5. The physical model of the new site was crucial to some students compared to the 2D aerial images that had been given or the 3D digital model because it represented a 2D image for the student. "*It is just always been flat." (*Sa1). Quoting Sa1:

> *"I think it would be more useful to actually see the thing in front of you rather than just seeing it in, well, really as a 2D image of a 3D model on a computer screen."(*Sa1).

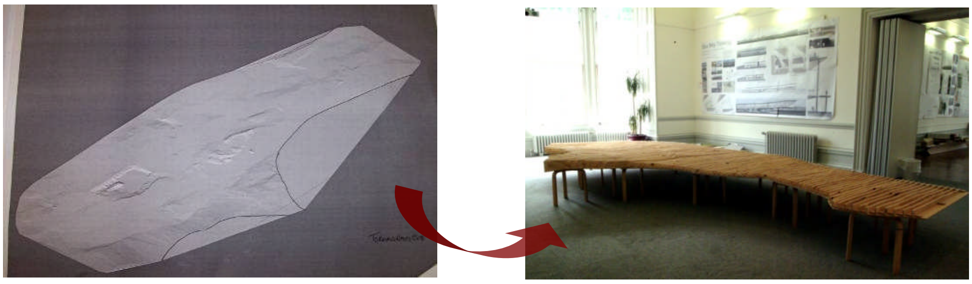


Figure 7-5 The new site digital model and physical model.

However, in the case of Sa3, the subpart of the modelling process carried the same criterion of speed but using scanned survey or drawings, as shown in Figure 7-6:

> *"I think in this case it was actually scanned drawings that we took because we just needed an outline as quickly as possible to make a model, so we just picked it up quickly. We did some measured surveys and then, but apart from that, you know, scanned drawings"* (Sa3).

In general, the focus was on one theme: a practical theme, by which the student previously gained CAAD skill, enabling the use of information as an input for the process of making a physical model. This extract revealed that students might produce or use methodologies that were not requested, or even encouraged by the project model.

3D physical model

3D physical model

2D CAAD Drawing

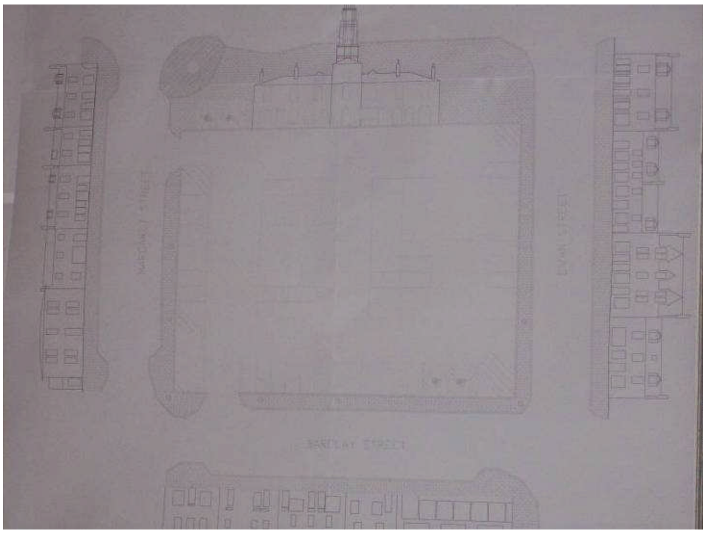


Figure 7-6 another example for the precedent study 2D CAAD drawings and 3D physical models.

Moreover, student Sa3 found no reason to model the precedent physically. The physical models were not seen as useful because they were precedents, not the actual site of the project and it is more common in architectural design studies to model what you are thinking of (design situation), rather than to imitate an existing object:

> "*The models, they are nice to look at but we did not need them for this specific project I find*." (Sa3).
>
> "*No. With the case study I do not need a big model (new site) for that. A small one would have done the job and even a model in CAAD or in whatever, SketchUp, would have done the job*" (Sa3).

On the other hand, student Sa3 emphasised which aspect is examined within a model:

> *"I think you can look at the model and see the site, but that is no good if that is not the element you want to look for. If you want to look at materials yeah you can see all the buildings, but the photos give you more information if you want to see what colour the stone is."* (Sa3).

It therefore follows that in the process of investigating the model, it was established that the precedent is a critical factor in medium (model) evaluation, but a medium could not give all possible elements of a precedent.

In contrast to Sa1 and Sa3, student Sa2 compared modelling to drawing as being a more active method than drawing. For example the practical experience of making the model, would identify many conceptual themes as a result of doing/seeing the model (in physical 3D):

> *"By drawings, you just can look at them, but if you're actually making a model you have to put a lot more attention in, pay a lot more attention to what is actually there and what size it is and stuff so"* (Sa2).
>
> *"building a model give out a very, very clear insight into what actually is in the centre, including all the other buildings and stuff that you don't necessarily do with just hand drawing or drawings."* (Sa2).

Model making gives a sense of the model created which is related to the previous view of "*put more attention*", as the interviewee emphasised that modelling gives a "*very*" clear insight into what is actually there. The model is shown in Figure 7-7.

the new town model 

the new town model 

the technique used 

Figure 7-7 the physical model of the master planning site.

In general, the artefacts produced (such as models, drawings or booklets), were useful in showing the student the different steps they had taken toward the production of that artefact. However, everything the student had produced was the result of a specific course of action that is process-based rather than artefact-based, although superficially students intended mainly to achieve the artefact without “knowing how” to get from A to D. It was also evident from the way they reflected on their actions from the beginning of the project until the point where they were interviewed, that the work they had been engaged in was process-directed (Figure 7-8). Being reflective whilst experiencing such processes or sub-processes does not necessarily imply that the students were fully aware of their usefulness or intentions, but it does demonstrate the value of reflection as a process.

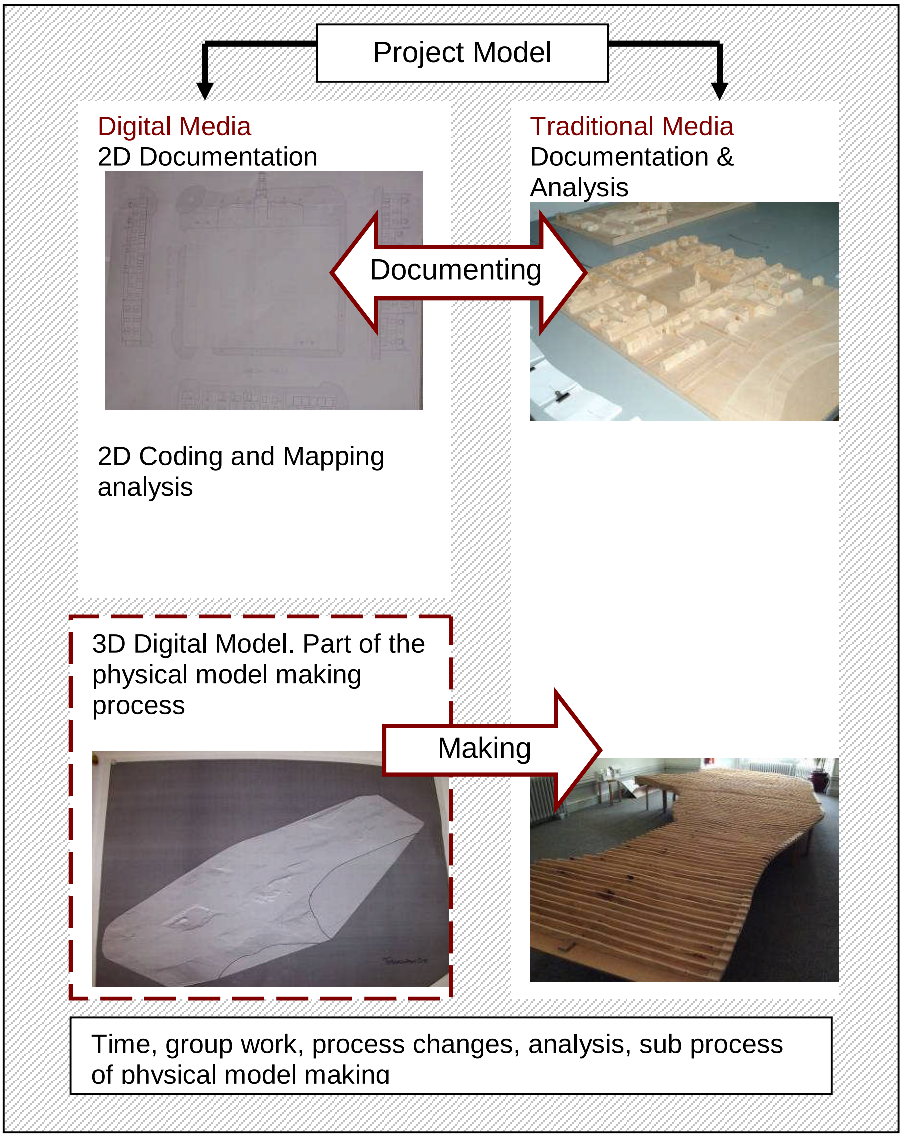


Figure 7-8 Media flow of the design process.

In brief, the students had started with the purpose of producing the required artefact, but had drifted through time and a variety of means to a process-directed way rather than an artefact-directed way. It is interesting to note that the precedent has been explored using three different mediums; site visit, physical modelling and filming an agreed route. Each has provided the students with a different level of understanding and has given them a different aspect to look at and explore. Using these mediums has led to the use of another, as the site visit led to the thought of producing a film. The film summarised and presented what was the most interesting theoretical theme or finding of the other media exploration, which was town development.

7.2.5 Presentation criteria

The analytical strategy used by the students was based on colour coding the different uses of the town, which had, in turn, some conceptual implications on students' thematic studies. With respect to CAAD's role as a designing tool or a drafting tool, the responses indicated that every tool (manual/digital) used, had a criterion pertaining to expression that is parallel to the purpose of representation, reflecting on what has been termed as *dualism* of architectural representation (Meenely and Banko 2007). However, this criterion is related to students' ability to design and communicate, claimed to be necessary for a student's communication process (Ambach 2006). The relationship between presentation (appearance) and any conceptual production should be clarified, as both have an inseparable set of criteria. That is students have related CAAD drawings with presentational criteria, such as "*simple*", "*clear*" and "*succinctly*".

Besides other purposes for using CAAD representation, presentational criteria were mentioned by the students to show that such criteria are important even at an early stage of the project.

> *"Just to highlight different types of buildings and different densities and I tried to keep it as simple as possible"* and *"just to show very clearly where the zones are"* (Sa1).

As a result, the clarity obtained enabled the students to develop a conceptual reasoning of what was already there:

> *"Work out in relation to each other, so you can see that the commercial was at one side of the plan, and you could see that the industrial was at another side, and then there was sort of open public green space all around. The purpose was just to show it very clearly and very succinctly, how these*

places work together." (Sa1).

Student Sa2 also related physical modelling with presentational criteria and the impression given by two contrasting words: *solid* and *cheap*.

> "Y*es, I suppose I am doing a timber model, (tutor's name) particularly did not want a cardboard model. I think it is better because it gives you work like solid rather than little cheap cards that you put together. So I do think it is better like that. "* (Sa2).

> *"We had to make a timber model. I think he was (tutor) talking about hard wood, you know, to look realistic. it would take far too long and money, ended up being MDF and plywood and timber pine which worked for us."* (Sa2).

This extract indicates that even with physical modelling there is a presentational aspect that tutors and students need to identify, alongside the other constraints of time and cost. Obviously, this criterion varies greatly between students and tutors. The studio tutor selected the timber model as part of the project model.

The technical theme of "making" the movie was analysed in terms of how the student (Sa1) executed it (equipment, point of view). Film is referred to as a representational material because of its role in the process of the review. Thus, design media effect is an inherited property of presenting information in architectural representation rather than an inherited property of the tool used. The flexibility of a tool is dependent on the flexibility of what is represented.

What is interesting though is that presentational criteria are learned through other examples from *magazines*, which allow criticism of other work on a surface level rather than apprising its relative meaning, structure and content. That is to say, imitating the presentational criteria without connection to the conceptual structure of the image or the magazine. The following extract indicates how Sa1 was influenced by other drawings. He said:

> *"I'm sure I will have seen somewhere a drawing of this type and it is stuck with me, I thought that this would be best way of showing some of the things."* (Sa1).

Student Sa1 acknowledged, "*I would say it was a bit of, for me anyway, the chosen media was probably one aspect and maybe (pause) from looking at other drawings* "*(Sa1).* Therefore, the drawings were the most influential factor in the project understanding, with respect to the information they conveyed and how they were presented. How others have presented information provided an important way of learning the best way to convey information and deciding on a style. Quoting the student: "*whenever I look at a magazine I try and look at the way people have shown information on a drawing and try, you know, to try, it gives me ideas for the future, you know, how to draw*". This extract gave an insight into how self-judgement plays an integral role in deciding on such criteria "*I thought that this would be best way of showing some of the things."* (Sa1). Surface approach to drawings and subjectivity is what presentational criteria are based upon.

7.2.6 Other influences on CAAD utility

At these early stages of the presentation process (parallel process), students were aware of the possible changes that may be requested. Therefore, they used CAAD as an easy platform to make these changes (colour changing) during collaboration with other students. Moreover, CAAD was used to overcome the differences in presentation criteria that may appear in individual preferences between the students. In addition, it was used as an easy way to make changes when each piece of work was put together for a group presentation for the review:

> *"We use different CAAD packages, because if we do it by hand and they didn't like the colour they draw it in, that would be another week's work really if, and on CAAD you click two buttons and it changes colour"* (Sa3).

Consequently, group work became an added criterion for student's preference to use CAAD within the studio context, which implicitly reflects the time needed for design routine tasks. However, a contrasting point of view was provided when sketching was mentioned under the same condition of group work. Sketches were considered as valuable because of the resulting variation and how this would convey the mood or feeling of the design situation.

> *"Yes, collecting sketches of the place is important"* (Sa4).

> *"Yeah, I think not necessarily for producing the drawings but for understanding the feel of the place, because if everyone in the group did different sketches, everyone had a different feeling of the place and once you put it altogether you have got the different atmospheres"(*Sa4).

Thus collecting sketches of a new place (site) was important not only for creating the requested drawings, but also for the understanding of that place. This refers to the fact that sketches are not only used for note taking but also to convey the feeling or the experience of a (new) place. Therefore, the students who presented quite different criteria within the same condition of group work, favoured CAAD and sketches. That is to say, CAAD was the tool where the criterion was uniting what group members have produced to reduce individuality rather than emphasise it. In contrast to this where the criteria were variation and character, sketches by group members were used to convey different feelings. Thus, media variation has an added effect on students' understanding as well as their process of production.

7.2.7 Understanding and recognition

At the beginning of the project, there was no identification of design related conceptual themes such as design problems or constraints as the students were obviously working on the precedent in a detached manner from the design problem due to the time constraint.

> *"We have done something similar, basically for every site we have analysed. I mean now that we are not building on the site it is probably different because we are just analysing some site and then moving on to something else, but you know we have done*." (Sa4).

When asked about the learning process he was experiencing, the student felt there was no difference. It was the same process he went through with every design brief and site, the only difference was that he was merely analysing without designing. The gap between the site analysis and designing was the difference, not the process. The connection between the current situation and the latter was difficult to be make at this relatively early stage.

However, at this stage student Sa1 did not think of the design work "*I'm not entirely sure yet"* but he thought that what he had done and his other project-related work could affect the next stage of design and thinking*." I have not thought too much about the design work yet and I think it could, yeah, I think so*." (Sa1). Although student Sa2 became more focused on one or two themes within town planning, she could not see the connection between this stage work and the conceptual progress. Her answers also reflected the fact that the next stage of their work was unclear and uncertain; this being the case in studio work.

At this stage, the student felt that there was no conceptual exploration:

> "*I do not think we have explored any design concept yet. It is no design whatsoever*." (Sa2).

With respect to the student's conceptual status of separation, student Sa4 said:

> "*No, because we do not have a design."(*Sa4).

> "*We were not thinking design because we were thinking we want data collection rather than design, I think our project will be design for the next stage. Design a model yes, but not design a design*."(Sa4).

After describing the design situation as part of the project model, the media used/ applied had been successful in revealing a new level of understanding of the studied precedent identifying emergent conceptual themes for the next stage. This was related to the chosen medium for analysing and documenting the project. Compared to the other participants, student Sa1 suggested a reasonable connection between what had been analysed in the precedent study for the new design in an attached manner (an elaboration on the student's reflection can be found in Appendix F, p. 377).

The students identified different sources of product, process, and activity that helped them to understand their projects and influenced their investigative work and project understanding. These were mainly the project brief and project model. Typical extracts were:

> *" I think because we did the actual zoning drawings …helped me understand Stonehaven more."* (Sa1).

> *"Was the model, it's been quite extensive by the tutor"* (Sa2).

> "*It is the brief and the other students, our tutors, and the visit to the site. They had an influence on themes and materials and stuff and had some influence but we are expected to be able to work on our own*." (Sa4).

This stage experience (learning) was summarised by conceptual, technical or practical reasons as students mentioned few themes (centre, material types, building style, town zones) of town planning. Which they had developed from the precedent and were aware that they would have to take these themes to the next level.

7.2.8 Summary

At this level of studio work, the students mostly recorded existing conditions of the design situation, which helped them to identify conceptual themes for the next stage. Students' reflection emphasised the practical and technical engagement with an artefact or a representation more than the conceptual intent of these different practices. However, through a variety of representations, 2D and 3D CAAD drawings and physical modelling of the precedents, the work in this stage was investigative in nature where the level of abstraction is high, looking at the general aspects of project types. There was a practical gap between what had been studied with what had been designed or proposed, that is the precedent study and the actual project. The features of the project model affected students' conceptual attachment to the two subparts.

Studio work has a dual aim which is both conceptual and practical. With respect to problem identification, students have worked through precedent studies to define their project problem. This process featured two aspects: a) representations of problem (precedent) analysis were mutually related to presentation, and b) the conceptual separation between the precedent problem analysis and the main project.

Within a design educational context, the project model would determine not only the design situation(s) but also the "best tools" for design engagement, which eventually would reflect the tutor's perspective as part of the project model. Such engagement should correspond to the students' level of design expertise as well as the students' abilities. Currently, most, if not all, the tools that were set by the project model were traditional or manual and hence time consuming. However, students brought other practices along in addition to what had been requested as part of the project model to speed up the making process/production. That is to say, that the students showed a tendency to select other media regardless of the purpose, whether it was influenced by a need for more understanding or another level of understanding. What the students used might be related to their academic set of skills or other skills that were based on socio-cultural, or digital design practices (through replacement).

CAAD's role and purpose at the beginning of the studio project can be summarised as follows:

1- to provide a means for analytical studies of colour coding that is based on other visual material (maps, surveys, photos and templates for physical modelling). These studies were based on representing real situations as part of a precedent study.
2- to speed up the process of design (drafting) and physical modelling.
3- to unite individuals' presentation criteria, and make the required changes.
4- to substitute by sketching whenever students' needed a variety of expression, a feel for a new place (insights).

Moreover, media utility in the studio context would primarily serve the learning perspective and its applicability for knowing-in-action. There are no opportunities for training the students to gain a critical insight into the utility of CAAD tools, and how students would be critical in terms of the used media. There is a need to elevate students' awareness of the used tools and their potentials by design-contextualised engagement.

7.3 Second Point of Reflection

The second point of reflection was in the middle of the studio design process. In describing the second phase work as part of the project model, the students had presented their proposals in a pin up review after considering the precedent study in the first phase. As a result of the second phase analysis, more categories emerged as CAAD was used frequently to present this phase work. Many of the features noted were based on student-tools interaction and the phase work which informed a better understanding of this interaction.

The analysis of the second phase data consists of four students: one female (Sb1) and three male students (Sb2, Sb3 and Sb4). A general description is presented in table 7-4. The second set of questions (set 2), in Appendix C-2 p. 363, was employed.

Table 7-4 the work description of the selected cases.

Cases	Description
Sb1_F student	Presented her work in both 2D CAAD and hand drawings, she prefers CAAD to draw in 2D but not in 3D, as she prefers 3D physical modelling.
Sb2_M student	Presented his work in 2D CAAD drawings of 3D abstractions, 3D Lego and 2D and 3D Hand drawing. He prefers to draw in CAAD as a drawing board to present and he has no 3D CAAD skill to actually model in 3D.
Sb3_M student	Presented his work in 3D SketchUp rendered images, he prefers SketchUp for early 3D exploration, CAAD for 2D drawings and use sketches for initial ideas.
Sb4_M student	Presented his work in 2D collage presentation which was paper-based, he prefers (Auto)CAAD for 2D and 3D drawings.

The first three students demonstrated similarities; all of them were interested in formalism, form generation and massing, and were working on the same project (the School of Art extension). The last student- Sb4 - was working on the master plan of a new town and had to face two problems since the last phase of reflection: understanding the scale of the new site in relation to the studied precedents and coping with the blankness of the new site. The findings are presented in the following sections:

7.3.1 Project model

With respect to the second point responses, each of the four cases gave different accounts of the same stage work to represent what they had done (actions) in words (reflection). The student process of "*knowing in action*" (Schön 1987) at this stage became focused on the student way of thinking with the intent of proposing scenarios. The student's reflection and practices took another direction that is representation intensive.

What makes this phase work is the representations used and their direct connection with conceptual intents. Student Sb1 described the second phase work primarily through the requested representations:

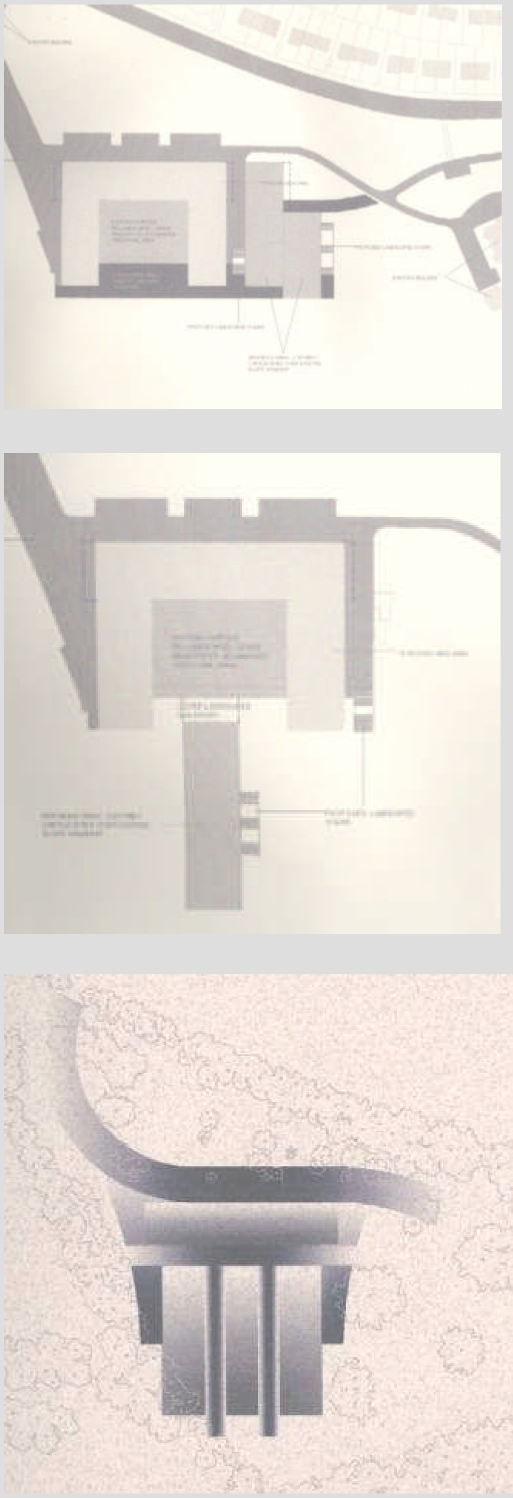
> "*It is not mass drawing so you can be more like I said smaller (CAAD drawings) and do sketches. I think you could be a bit more analytical about your work and you sketch that before you get into CAAD. So I'm enjoying it a lot more I think." (*Sb1).

Comparing the required representations for the second phase work to previous years by the student, two criteria emerged: (1) the level of abstraction of the created drawings, and (2) the size of the printed representation. This change enabled the cooperation between CAAD drawing and sketches in a continuous blend, despite the fact that sketches were the predominate drawing. However, these criteria seemed successful in engaging the student with CAAD drawings on a higher level of abstraction. As such, the small sized CAAD drawings suggest a deeper level of engagement in conception rather than distracting thought.

Moreover, the other specified aspect of this stage work pertains to the project model, wherein a research stage precedes the design stage:

> *"I think the tutors before start designing which is quite good, they're not putting us straight into (design)...there would be more background and, as I said in other years we've always had to produce these large scale drawings we're not really used to it then, and this year it's been everything kept small and it's more personal".* (Sb1).

Sb-1 Developing various design proposals using sketches.



Sb-1 The design proposals represented using CAAD software programs.

Figure 7-9 Sb1 visuals at the 2nd phase of studio reflection, mainly 2D.

In fact, comments such as "*would be more background"* and we *"had to* *produce these large scale drawings we're not really used to it then"* define to some extent the process that this year's project model had outlined. Wherein the drawing scale (its final printed size) is affecting the student's attitude positively by making her feel more analytical by this "personal" and "informal" presentation process. Consequently, affected the time they spent in conception, instead of spending the time doing large-scale drawings which eventually need more details. The student stated: *"And we've got more time I think to grasp an idea."* (Sb1).

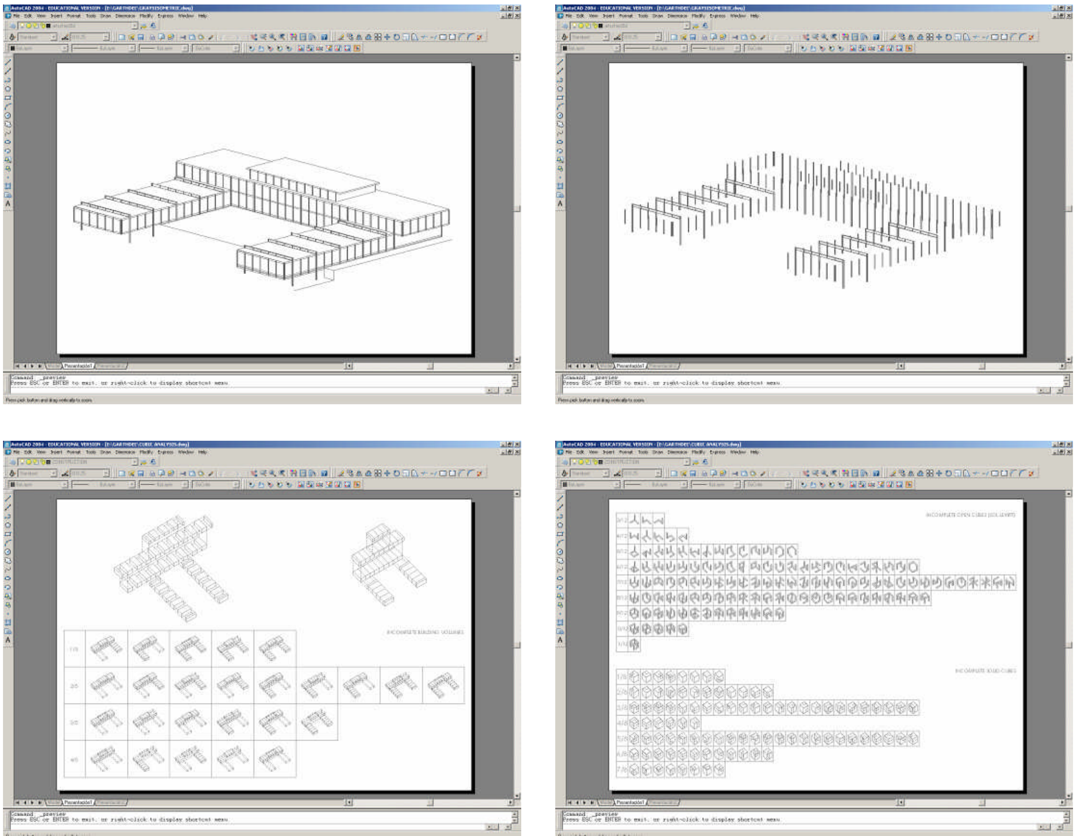


Figure 7-10 Continual analysis of the existing building with respect to the student's (Sb2) conceptual approach.

Student Sb2 (Figure 7-10) had described the former phase work by the type of drawings he had produced, and how these visuals conformed to conception. Sketches were mentioned for exploring "*basic ideas*" then followed by "*block sketches*," i.e. 3D sketches (shown in Figure 7-11), were made as part of his intention to explore one potential approach (formalism) to architectural form making and its potential in relation to the design situation (The extension of Gray School of Art).

"At the moment I have done some (3D) sketches, it is for basic ideas. Context for the project, it is in block sketches, block planning. And I have explored (them) for ideas and then I've put them into AutoCAD in two dimensions." (Sb2).

This extract highlights two things: the first is sketches concorded with basic ideas and 3D blocks, and secondly the move to CAAD was made after 3D sketching into 2D CAAD. The move from sketch to CAAD is considered an early action for someone who is skilled in 2D CAAD drawing but not as skilled in 3D CAAD. So to draw the same intent in CAAD, he had to use a basic method (similar to if he drew it on a drawing board by a T-square) in drawing 3D objects in 2D coordinations (X,Y) to draw the 3D blocks he was exploring, shown in Figure 7-10. What complements this observation is the use of Lego to explore 3D physical modelling of the potential abstractions.

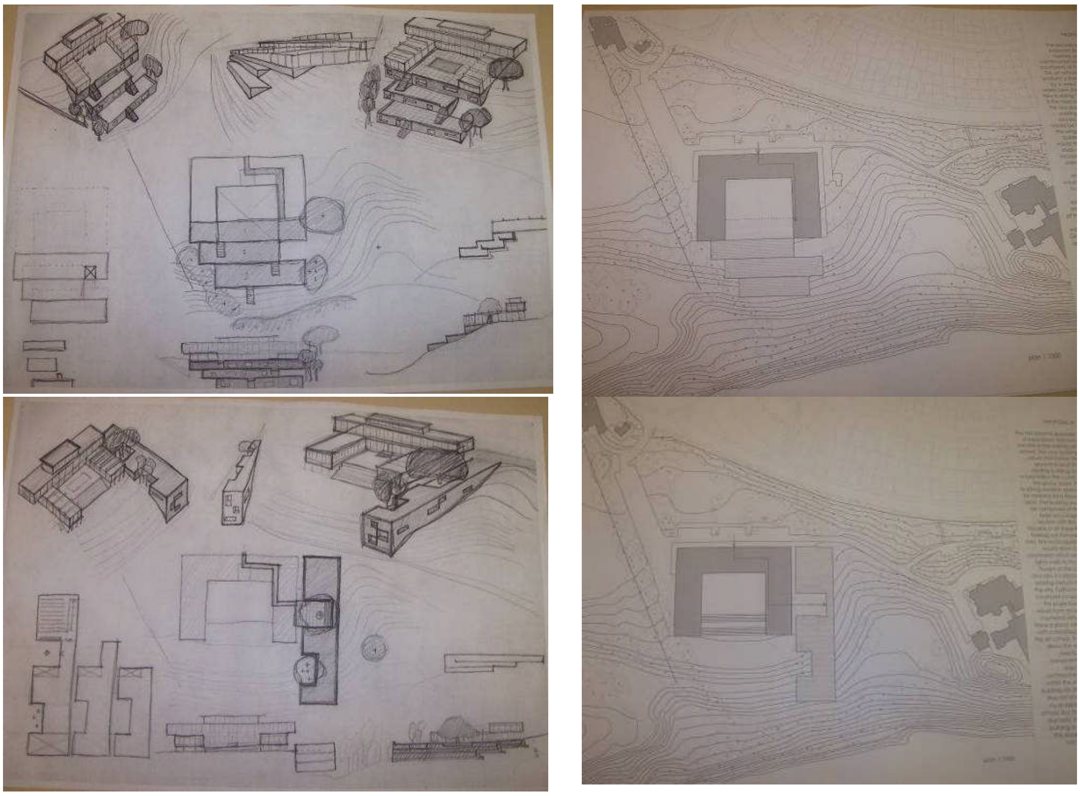


Figure 7-11 Sb2 visuals at the 2nd phase of studio reflection.

Student Sb3's extract shows a high level of uncertainty which can be concluded from the characteristics of his work, or as a result of the reviewers' feedback. The negative feedback he had received after using SketchUp (rendered) representations:

"I'm not really too sure. I am still kind of still trying to find out if I have my own sort of style or strength, the sort of different genre that my design might just then fall into. I think still at this stage there are so many options that it is

going to take a while before any ideas really start, you know, before a process that will come together and then buildings will start and maybe having a style." (Sb3).

Student Sb4 also compared his project with projects from previous years but in a different context from Sb2, as he considered the project size (urban) and its relative level of abstraction instead of the produced representations. After three weeks into the project, the student felt detached from designing and still saw the project in *general* terms:

> *"It was kind involved the master planning, so it is kind of, it is still quite general compared to what we had done in previous years. But there was no detail involved and stuff. It was all kind of general, kind of mapping/massing more than anything else."(*Sb4).

The project feature (size) had two effects on the student's behaviour: firstly, the state of the experienced design as mentioned earlier, and secondly, the way the project model had been tackled by proposing a *paper* based technique. Quoting Sb4:

> "*Had kind of different bits chasing over them to get, kind of, how towns develop and stuff like that. To get the scale and that can go on forever, because you've actually taken some of the bits, that you like and putting your own bits in and stuff like that."(*Sb4).

At the beginning of the project CAAD drawings were produced for the precedent, therefore digital material for both the precedent and the new site were available for the students. However, they could not connect both and create the same benefit of collage (paper-based technique) but in a CAAD platform. Consequently, the project model, and specifically the tutor's knowledge and methods, influenced the student's common process of sketching as well as CAAD by proposing traditional methods of making.

Student Sb4 also referred to the tutors' role in clarifying the next step of the project and therefore the work that needed to be done. This controlled the flow of the process and the student's certainty.

> *"I'm not entirely sure what is (tutor name) planning because … I think he's kind of planning to make one big master plan for the whole group to work from. So, I think kind of we need to carry bits of it forward and kind of see what happens after that."(*Sb4).

These extracts also highlight the role that a tutor plays in the context of any project model and how certainty levels may be determined by the tutor's role.

7.3.2 The used media

By now, design media variation was obviously one of the key characteristics for this phase of the studio project and the contemporary context of the studio. The students specified the following media and format, shown in Table 7-5: the most frequently used media for their project exploration of the second phase.

Table 7-5 Media used for project investigative studies: 2nd review

<table>
<tr><th rowspan="2"></th><th rowspan="2">Media</th><th colspan="4">Cases</th></tr>
<tr><th>Sb1</th><th>Sb2</th><th>Sb3</th><th>Sb4</th></tr>
<tr><td rowspan="6">Most Used Media within the project model</td><td>Hand drawing</td><td>+</td><td>+</td><td>+</td><td>+</td></tr>
<tr><td>CAAD drawing</td><td>+
AutoCAD</td><td>+
AutoCAD</td><td>+</td><td>+</td></tr>
<tr><td>Physical model</td><td>+</td><td>+
Lego</td><td></td><td>+</td></tr>
<tr><td>Digital model</td><td></td><td></td><td>+
SketchUp</td><td></td></tr>
<tr><td>Paper Collage</td><td></td><td></td><td></td><td>+</td></tr>
<tr><td>Site Visit</td><td>+</td><td>+</td><td>+</td><td></td></tr>
<tr><td rowspan="2">Other Media</td><td>Verbal discussion</td><td>+</td><td></td><td>+
get broader view about the site</td><td>+</td></tr>
<tr><td>Photomontage</td><td></td><td></td><td>+
Photoshop</td><td>+</td></tr>
<tr><td colspan="2">Format</td><td>2D Sketches
3D SketchUp</td><td>2D in 3D
Isometrics
AutoCAD</td><td>3D
SketchUp</td><td>2D and 3D
AutoCAD</td></tr>
</table>

In phase one, the media used was project-based rather than student-based. This had pedagogical objectives rather than creative or designing objectives. However, other mediums were proposed for ideas, (Table 7-5) such as "..*just really chatting with people, other people in the group and things about, you know, other people's ideas and other people's concepts with the site*" (Sb2). Further to the mentioned media, the studio context provided another medium for interaction which had the same impact on students' understanding as other students' ideas, concepts, drawings and discussions.

7.3.3 Means of design exploration

7.3.3.a Design problem

At this stage, the students were more confident in identifying the design problem compared to their first point of reflection. Moreover, this was also the case within the same phase reflection when they were asked about their concepts, and if they had explored any design concepts. Defining the design problem (or the partial problem) within the given design situation seemed easier to accomplish than defining a design concept. Students' responses were explicit in identifying the problem in context, such as "*the views are obscured, it is hard to add (to) the building without taking away the views*" which implies a higher level of certainty compared to the first phase of responses. Typical extracts were:

> *"The existing building may have to change, I think. It is hard to extend the existing building. So I think adding the problem that the views are obscured in a way by what is there, at the moment It is hard to add (to) the building without taking away the views that you want to keep." (Sb1).*
>
> *"The problem was of putting a new building on the site which was in respect of the existing building and the landscape." (Sb2).*
>
> *"It is just the topography of the site is just, you know been heavily wooded and with the Art School there is not a great deal of space for putting an extra, another building. And the areas that are available are heavily wooded, as I said and the topography is, you know, quite steep." (*Sb3).

As a result, the problems identified were found to be useful in guiding the student's further exploration. This suggests that they are engaged in the design situation as they felt that:

> "*So getting your area but without obstructing the site too much and keeping what is there really".* (Sb1).
>
> *"And I think it is going to be quite difficult to actually place a substantial building in there without maybe taking away part of the existing Art School or incorporating that into it as well into the space so, yeah."(*Sb3).

However, one response (Sb4) provided further support for the same point but with a different design situation, the new town project:

> *" … very different from the other ones, in that Tornagrain was a problem itself, because it's a blank field so it's not as if you can kind of like, you can find a particular problem with it. It's totally different, but I think, kind of, we were trying to use as much green to give high density as such" (*Sb4).

As a result, the student suggests creating problems instead of reacting to them as propositions or constraints to guide the student's further exploration:

> *"Because it is (blank site) … we can set up problems ourselves, wherever, you know." (*Sb4).

One conceptual theme identified by Sb2, was the building form and its relation to the site typology which had been explored in CAAD and hand drawings, that is massing studies. Aside from this, some design aspects were checked that were computer-system dependent, such as *"just the areas and the scale*" (Sb2).

7.3.3.b Exploration

Within the studio context, another phase of project exploration is gathering information to enhance understanding and reduce ambiguity. Project understanding occurs through exploration in a process of problem solving, through which understanding is achieved and the current status is perceived. Students' responses identified two types of conceptual exploration: active and passive. Both types of exploration educated the students about the design situation as a preliminary phase before informing their conceptual understanding and design. Two students (Sb1 and Sb3) suggested that effective exploration had to engage the senses as well as the feelings:

> *" I looked at the site, we had a walk form the school, me and two of my other classmates, this is what's there, and have a look and just how you feel, and I felt that when you walk through you don't actually realise what kind of landscape they're on. How stepped it is."(Sb1).*

> *"I really explored it by going out there, and actually exploring it, and experiencing it for yourself, you know, photographs and actually just going out and spending some time walking around the buildings, getting some general ideas of where I think things could go and, you know, taking notes of any wooded areas and any muddy areas or grass."(Sb3).*

It is as if exploration had two meanings in the students' terminology. The first was of a physical nature (engaged by their senses) when the students physically went to the site and evaluated the design situation in respect to the design brief and requirements. The other one was of a mental nature when the students engaged in the medium of representation. However, this exploration resulted in identifying different aims and intentions that were handled as "concepts" that need further exploration, design and development. Typical extracts were:

> *"In my main concept I wanted to be able to walk through this building and feel exactly the site you are on. You step down and as you go down through the building, you know you're going down into the site. I wanted to try and express that in the building."(Sb1).*

> *"Yeah just by walking through the building and walking down the site, taking a walk down the site and through CAAD sections. Looking at the sections see how it has set already, and seeing the volumes of the space that we have to work with. I do not want to obstruct the views; I thought when I keep the views and step the building down."(Sb1).*

In brief, the extract above describes how active (physical) exploration initiates conceptual ideas and propositions are moved forward to the next step of designing where these ideas would be shaped. Whether a site visit was being used or a computer medium to explore the design problem space, all students explored the same aspect of the site "typography". In turn, this aspect of site exploration had themed the students' responses on different levels, for example, "landscape," "stepped" and "walkthrough".

7.3.3.c Other means of exploration

This exploration took place again on the level of CAAD representations, whereby a point of reference was provided for the students to triangulate what they had learned actively (site visit) and the given drawings through surveys. At different points in the process, students were given CAAD digital drawings (representations of reality) as a reference source for the present status and dimensions, e.g. survey or drawings (site or existing building). Despite CAAD's accuracy, it was observed that students tended to check and hence correct the given drawings (which were not created by them, in this case, by the University Estates Department). This was noted in the first and the second phase responses. One reason for this was the drawing accuracy when compared to the surveyed data of the precedent (1st phase) or the actual site of the design project (phase two). Another reason was the poor quality of the given drawings with respect to how these drawings had been created. A typical extract was:

> *"We've got the existing drawings in CAAD but they were all wrong, the lines were all wonky, there were heaps of lines under lines and you just couldn't fix so we went over and surveyed parts of the building and took photos and drawings and sketches. And you actually got to appreciate the building a lot more." (Sb1).*

Poor quality CAAD drawings and inaccuracy initiated a backward move to undertake more active site studies "*we went over and surveyed parts of the building"* using various tools and representations, for example "*took photos, drawings and sketches"* which had an impact on the student's appreciation (understanding) of the existing building. Such initiation can also be achieved by drawing the site and site attributes by students themselves (a deviation from what the traditional design project would imply in terms of CAAD's role) where students could relate the real to the virtual in a process of visual conceptual association. However, depicting reality was found to be the common practice (or preference) among students even if they were given CAAD drawings. How to approximate the real and the virtual representation of a design situation is important and critical; students' critical appraisal of CAAD drawings set a further course of action in the real world.

This point supports the fact that drawing is still being seen as a personal piece of work even if it was created in CAAD or depicting an exciting building. Quoting Sb1:

> *"So it was just through basically studying the building, the personal work with the drawing and we had to survey." (Sb1).*

Another important factor in design exploration (Sb2) was studying the relationship between the building and the site. It was important to examine the possibilities of the relationship between the design requirements and the student's impression of the proposed approach:

> *"Well I explored various ways of putting the building on to the site, that would meet these requirements that would deal with the problem. Various schemes that were respectful of the existing building were also quite integrated with topography of the site." (Sb2).*

Setting constraints was therefore another factor in exploring possibilities within the site dimensions, typology and the student's focus of the design proposal.
Student Sb4's extract shows that with time the student became more aware of the processes he had been through from the start until this stage:

> *"It's kind of few different processes of, like we've kind of tried some things and looked at the case studies that we'd done at the start and then kind of discussed them, and then we actually did our collage".* (Sb4).

7.3.3.d Concept

Student Sb1 and Sb2's responses were positive to suggest that there was some form of conceptual exploration, though one of the two students changed his response saying that: *"They are conceptual."* then changed to *"No, these are various options of one concept." (Sb2).* Student Sb4 was not sure whether what he had looked at was a conceptual option(s). Indeed, he thought that changes were made as a result of exploration:

> “*we kind always had little kind of changes from the design but not really.” “No, we are maybe looking at couple of possibilities for the same one but nothing more than that really. It is more kind of what happens if you do this way? No, we will do this way instead. So there wasn't many big changes round that, or alternatives.”* (Sb4)

However, these responses overlapped with CAAD meaning and utility in the conceptual design, quoting Sb3: *“Just really conceptual ideas, conceptual sketches really, but done on the computer so, yeah just conceptual ideas, really basic conception.”* This also refers to the difficulty in connecting sketches or conceptual ideas to the *computer* as a tool for exploration. In the next extract, the student (Sb4) classified *computer* into CAAD and SketchUp: “*but I would not use CAAD for that. I would use, I draw just quick sketches to, you know, come up with an idea and then take it into 3D, so take it into SketchUp and then it is much easier again just to move things round and to have different shapes and things so*.” to be explored in CAAD (SketchUp) but not AutoCAD.

7.3.4 Early move to CAAD

The move from sketching and hand drawings to CAAD was evident in the students’ extracts by the degree to which an idea had been developed. As such, arriving at this point mentally in the process, initiates a need to employ CAAD in exploring the idea to scale, or the necessity to employ 3D exploration that is SketchUp-based rather than AutoCAD (Sb2 had explored abstract forms in AutoCAD).

> *“Yeah hand drawing and sketches and just little doodle and to an extent putting it into CAAD after that. Just having few fixed ideas. That was it. It is just exact same drawing but just taking the different ideas into CAAD like this is a shading have no line in it! Like hard mass turned off to shading only not planning.”(Sb1).*

The third student (Sb3) emphasised “*how*” he would carry on concept exploration in terms of the methods and mediums. Starting with sketches, *“Well I usually go for just basic sketches as most people would.”* The student’s extract shows a tendency towards 3D conceptual exploration methods in both mediums; physical: “*with a little model*,” and digital medium (SketchUp): “*also quite a lot into the SketchUp core 3D on the computer.”* However, this student preferred modelling in a digital medium over sketching and physical modelling, for its ability to “*to get a better idea of 3D spaces and of course light and material and things.”* He did not show the spaces in his proposal. Instead, he concentrated on the massing of the proposed extension.

The degree of an idea development was also related to CAAD programs separation in AutoCAD and SketchUp. Frequently, AutoCAD concorded with "working drawings" and SketchUp concorded with conceptual exploration or 3D exploration. This reflects the different nature of the software in the eyes of the students as separate tools for different tasks.

> *"I was kind of rather to sketch things up, and then take it to CAAD (put it in CAAD), I would move things about and check them off and planning it through before we would be able to put it into Photoshop.", "It was more like line things up and be able to move them quickly and stuff like that." (Sb4).*

Some of the strategies mentioned are in agreement with CAAD such as: moving things about, lining things up, tweaking. This suggests that using CAAD for exploration implies certain strategies that are computer based, e.g. copy and paste, rotate and move which may reveal unexpected visual formations by the immediate feedback.

> *" it was really just kind of laying out the town and just seeing where the things worked best I mean all of the time it was done on paper to begin with and then it was just done in CAAD after , and maybe tweaked a little bit and stuff. But most of it was done just on paper … because it's a lot quicker to kind of scribble a bit of paper up and throw it away.*" (Sb4).

These extracts explicitly refer to a process between sketching and CAAD. A process of interlinked drawings that starts either way; from sketching to CAAD or proceeds from CAAD to sketching. How CAAD utility is bound to the student's need is one important aspect of CAAD utility theme.

> *"I think it is going to become really quite important to designers in the next little while anyway. It is starting to become more popular now."*
>
> *"I mean I only started using it on my year out, when I was out working. A couple of guys in the office were using it there and I sort of picked up on it. You know I thought, I saw, you know, here is a program that is going to be that is going to really help you come up with good ideas quicker and give you more in depth, look at all the different elements that we have been talking about"* (Sb3).

Students' responses have revealed various interesting reasons for choosing CAAD at the early phases of project work. Mostly pertain to personal preference and motivation, one of which is feeling comfortable using CAAD*:*

“I feel comfortable working with them (CAAD tools) and I don't feel that I have any restrictions.” (Sb1).

Such opinion was gained through engaging actively in using the CAAD program (AutoCAD in this case) for a long time. For design purposes, it improved the student's level of confidence as they were able to recognise that certain limits do exist but they also knew how to overcome those limits in a design context.

“*I've worked with the program so long. I know what it can do and my design will not be influenced by using it. I find that if you are learning the program you are restricted by what you think it can do. But I know that, I know CAAD is limited but there are ways in which you can work with it and then I use CAAD and use SketchUp and you can scan things and then work with it again in CAAD. I find that my design will not be changed because of the program I used.”* (Sb1).

“Really just because, you know, I understand it. I know how to use it, so I feel comfortable designing with it.” (Sb3).

Another personal preference was mentioned by the student Sb2 of 2D drawing which was based on comparing drawing in general and sketches to physical modelling “*I prefer drawing rather than model making for example.” (Sb2).* In this case, the student explored the same design theme using Lego bricks to make physical models of form variation (figure 7-12).

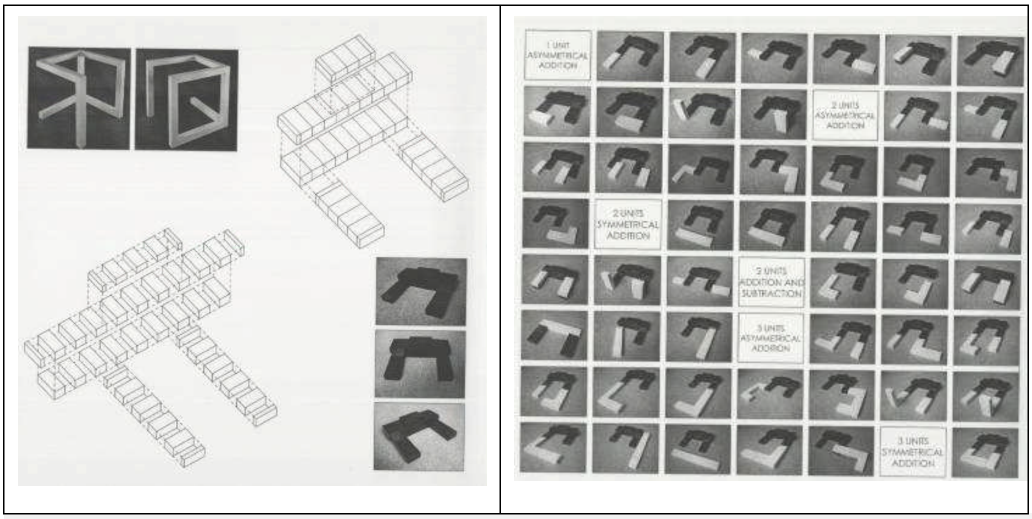


Figure 7-12 Sb2 Analytical studies of the existing building using 2D CAAD and 3D Lego.

However, students’ preferences to choose *design media* had no relationship with other aspects like design brief or design situation as “.. *this is the only way I would deal with any project.”* (Sb2). Sb3 also confirmed this when he said that;

"this would be the way I would probably do it anyway." This suggests that habitual practices were forming based on personal preferences along the design model engagement and progress.

The fact that practical habits were starting to form with respect to CAAD, is also reinforced in the following extracts:

> *"I often do. I have several occasions where I have pinned up in the first review and sketch stuff, it has almost always been in CAAD or some form of CAAD."(Sb1).*

> *"with SketchUp you can actually set up your lighting conditions, so of course you can maybe go onto the site and see how they are sitting and then also see the lighting conditions that you are going to get from that site in that position - condition. , which of course is a great help, you know. It cuts down a lot of waste of time that you might sit and design something and then find out the light is not quite right or you wouldn't get the light so you would have to move it, whereas you can do everything really instantaneously on the computer ."* (Sb4).

Within the same process of conceptual design, communicating design ideas has two different roles: communicating (ideas externalization) to one-self (interact with ones ideas) and communicating the same idea(s) to others. Each role would imply a different kind of function, message, quality and content. These different roles are being merged within CAAD representations. While the student is working on early conceptual options, he is thinking of the other role spontaneously.

In general, students used CAAD for presentation to reflect on their conceptual propositions in the final review. As mentioned previously in section 6.2.4, CAAD was also being used early as highlighted by four students who had used CAAD for presentation. However, CAAD engagement was on the surface level of showing and presenting the emerged ideas and themes.

The students' responses reflect *keenness* to move from hand drawing, however only 4 students moved to CAAD drawing. As such, the students are moving from what had been experienced and defined as flexible and fluent into what had been considered, in most design studies, as restricted. However, it does not have to be felt as such by the students themselves: the move is defined by other tendencies, for example their CAAD skill level, 3D preference, the project type/size and the required enlightenment.

One student defined the phase of movement as “.. *once I get past the structural idea stage I like to put it (in CAAD)”.* Why does this shift happen? It belongs to the many aspects of concept exploration in defining boundaries, constraints and in sparking creativity as well.

Another factor is the scale: *“I like to work in scale. And I like to know that what I am drawing is correct.”* Student Sb2 has related scale to the understanding of an exciting building “*it allows me to do quick drawings to understand the scale of the building”* referring to her method in using CAAD is important here.

Here she refers to CAAD terminology such as “correct”, “right” and “precise.” Interestingly, scale felt important to her at this early phase:

> “*I like sketching for ideas but then once I've got a few ideas, I like to know that I can take down and work further to know that I am drawing it right and the right scale and I like to do it precise.”* (Sb1).
>
> *“Yeah these are conceptual, and it just took 10 minutes to do that, so once you've got the main site, all that's standard and you just add and you just get and add five different concepts.” (Sb3).*

The student’s (Sb3) response reflects another reason for their keenness to move to CAAD early. It “*is a lot easier to present ideas instead of sitting and sketching down things”(Sb3). And* in terms of presentation: visualisation is important for inexperienced designers:

> *“[instead of] having a little arrow that says this is going to be a concrete wall whereas in SketchUp you can actually put the material on the concrete and then it is there in front of you, I think it is easier to read and it is easier to get ideas across, sooner on the project” (Sb3).*

The student (S4) also mentioned other presentational aspects of using CAAD early, which were speed, modification and neatness:

> *“ just use … kind of, the speed you can do it at and the, kind of, the fact that you can delete, you can delete things without you having to, kind of, rub them out and make a mess.” (Sb4).*
>
> *“I do. I always get end up using it even though sometimes I think I should suppose to do a couple of sketches. I think, kind of sketches, it's easier to do a quick sketch to kind of show what you're trying to do … but then, you are trying to do it neatly and quickly it comes out a lot better and quickly in CAAD.” (Sb3).*
>
> *“I often do. I do not think I have several occasions where I have pinned up in the first review and sketch stuff, it has almost always been in CAAD or some*

form of CAAD."(Sb1).

"Because I find it , well, I know how to use it so I find it easy to use, and I find it really effective as well. As I say, you know, you can model materials very easily, you can model lighting conditions very easily and it just gives you a very quick, and quite detailed overview of a certain idea so instead of spending maybe a whole day looking at one conceptual idea you can mix and match and choose things and I think it is a lot quicker." (Sb3).

If the majority of the students perceive CAAD as an easy tool for "seeing" their ideas, then what are the implications for the studio tutors? When the reviewers were confronted with a SketchUp presentation of 3D massing options, Figure 7-13, it was refused as a material for dialogue and it became obvious to the students that tutors bring their beliefs, methods and preferences to the studio or to the dialogue. Quoting the student:

"I think it depends on the tutors and it depends on their way of working. Because some people, you know, will still be working in pencil and hand sketches and things, whereas others may well be, you know, up to date on their 3D modelling and things, so I think it just depends on who you talk to and the way that you describe it." (Sb3).

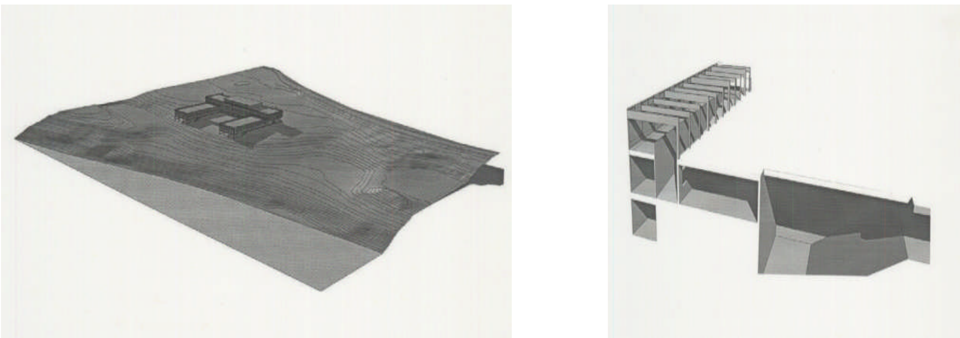


Figure 7-13 Sb3 presentation using 3D SketchUp images after changing (faking) the appearance.

In response to this to initiate such important dialogue, the student may change the expression of his ideas to suit what the tutor thinks is best. Faking the appearance of a representation will not solve the problem of the content. The dialogue should continue to make it clear to the student that it may be related to CAAD rendering images but it is mostly related to the content. In this way, the student will learn any bad influence the chosen media might have on his design problem solving.

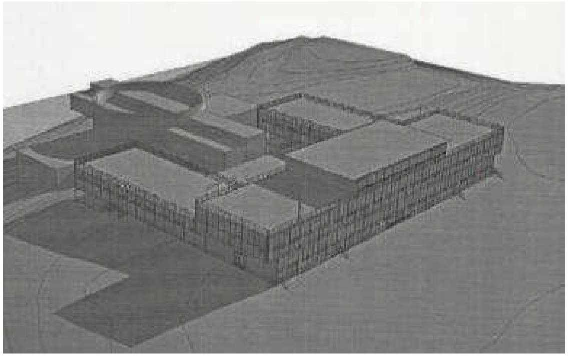


Figure 7-14 *Sb3 rendered image (SketchUp) of the proposed extension and the existing U- shaped building.*

Indeed, student Sb1 presented her work in 2D CAAD massing and her work was subsequently appraised and “enjoyed” by the same tutors. Quoting Sb1:

> “*[Tutor’s name] looked at my drawings and he enjoyed them, he thought they were very nice the way they were drawn,” and “it is what they were expecting for that day”* (Sb1).

However, on the level of content, all students confirmed that the reviewers thought, “*that (they) have gone too far ahead and (they) need to go back and study the studio space before (they) start building a school.” (Sb1).*

Expanding on the aspect of dualism (look and content), the student felt confused by the way reviewers criticised her work through the representation.

> *“Yeah, you get confused. They might say the drawing is nice and it is good and you will get praised, but the ideas and the way you’ve gone about it, like the actual concept might be wrong. Yeah it is a bit confusing sometimes but we have kind of learned over the years that one thing might mean another and the drawing itself might be good but the content might be wrong. Yeah you need to take it at face value I think.” (Sb1).*

No design-oriented strategy within CAAD teaching practise led the students to consider false criteria as the main criteria, which deceived their judgement system. This should be discussed in the light of the continuity of technology development of CAAD and other means, as the easier it becomes to use CAAD and the more students default to this method, the more problems will arise in the traditional context of the studio.

7.3.5 The drawing purpose

In relation to the presented drawings or the review presentation, students' responses revealed that producing CAAD drawings for the review presentation was useful in various ways. Sb1 revealed the following points:

- Analytical: "…*analyzing the determinate problems,"*
- Physical engagement with ones thoughts*: "instead of having things in your head … having it physically down on paper to discuss things and once you see it, it's different, once you draw it and see it then once you've finished you might decide, no that's wrong, but at least you've done it and you've got more of an idea.."*
- Physical engagement leads to verbal discussions
- Identifying new design problems: "*and then you can look at it and determine the problem for future areas I think, and determine which one might suit the site best."*

As a result of how drawings are useful, viewing and discussion facilitated both decision making and problem identification. Student Sb2 revealed how the produced drawings were useful "*They're to show basically how the scheme is being integrated with the existing buildings. It shows the scale and the form of the next building to the art [Gray School] building"* (Sb2).

- Show conceptual design options (relations with the design constraints in term of the scale and the form).

Student Sb3 revealed how the produced drawings were useful:

> *"What is going to be acceptable and what is not and the sort of … even the scale of the building I think. You know, what is the size of a building that you could not get away with, but, you know, that is going to be suitable for the site, and then maybe take my ideas further from that, so initially get an idea of the, you know, just the lighting conditions and maybe even the topography and everything, so just really getting a better understanding of the site I suppose, just in general"* (Sb3).

- Better understanding for myself: ""*just really to give myself a better understanding of which kind of forms will suit this site".*
- What is going to be acceptable and what is not.
- The scale of the building.

- Take my ideas further.
- Initially get an idea of the lighting conditions.
- Initially get an idea of the Topography.
- Just really getting a better understanding of the site, just in general

7.3.6 CAAD impact

Students' responses were positive, agreeing that working with CAAD would keep their thought-flow going as this flow is facilitated by drawing more than anything else. One of the students (Sb2) highlighted, however, that this flow has to be assisted by medium switch. Drawing is the common sense of thought flow in either platform; paper or CAAD, but medium switch provides the thinker with overarching visual abilities, in the sense that what is being seen on paper drawn by hand is different when it is seen in CAAD.

> *"Yeah, because once you see it on CAAD you may go back to draw again …look at the result of the computer drawings and then you go back to CAAD and change it, may be". (Sb2).*
>
> *"Yah, It makes you think all the time. You know when you are using it you can set your drawings up and then you can see instantly if there is a problem so that sets you off thinking oh how can I sort that and then, you know, you can just really sort out any errors quite quickly on it so."(*Sb3).
>
> *"Just because I think it gives you a more general overview of the whole, your whole site, you know, you can actually when you are sitting looking at it you can twist the model round and turn it and get different views and different ideas, whereas if you are just sketching on a piece of paper you can come up with a basic idea but you can't really put that forward to someone as what they would look like, you know, in one certain aspect or another one, whereas on the screen you can twist and turn the model and … you have got all your ideas and all the views there."(*Sb3).
>
> *"Sometimes, not always. Sometimes you find it can just occupy you and you don't really think" (Sb4).*

The following extract shows how student's level of abstraction in relating design exploration within CAAD medium. For example what material would suit the designed building, was found to be based on the appearance of the material rather than its physical characteristics and its influence on the design:

> *"One of the main issues I think with this project is going to be the way the building is built and the actual materials used and if you are going to try, you know, merge it in with the existing building and the landscape then of course*

> *the choice of materials is going to be important.", "How would these materials affect the site and things." (*Sb3).

Appearance should not have been the main deciding factor in choosing material, rather it should have been chosen according to its properties and material characteristics. Does this reflect the student perception of the term "material" as a design issue, or the student's surface approach to such design conceptual themes? In addition, CAAD had given the student a false impression of how to decide upon using a specific material which cannot be judged simply by such attributes as colour values or how it looks in terms of CAAD graphical quality.

Students should be trained to overcome such attributes at the early phase of such consideration and learn to be reflective. If they had been trained to have a critical eye for design, they would be more aware of the right timing for detailed levels of inquiry.

Through the studio project model, the students' process of comprehension could be characterised as superficial, in terms of the design issues. In turn, this was applicable in CAAD utility within the same model. As such, CAAD was examined in the studio context, directing the study towards the underpinning design related issues, which were practically observed and theoretically revisited within that educational context.

7.3.7 Students view of CAAD

The students (Sb1, Sb2, Sb3 and Sb4) agreed that designers are using new media to find a *physical formation* or composition to produce architecture that looks relatively interesting or new and they agreed to consider CAAD as one of these media. However, one student (Sb2) ambiguously said: *"there are people who do that.* " He did not refer to himself as one of those "people" or specify whether these people are designers, students or experts. While the research question was looking for a meaning for physical formation that is CAAD-based within students' perception, instead one student (Sb2) responded "*you need one (CAAD) to do your presentations on."* That is representing what previously had been formed physically. Another response (Sb3) showed the transferable (practical, contextual) knowledge of CAAD perception within an architectural practice: *"I think it is going to become really quite important to designers in the* *next little while anyway. It is starting to become more popular now. I mean I only started using it on my year out, when I was out working."* (Sb3).

In the light of this stage review and feedback, the students were asked whether drawing the same representations (options) by hand would make a difference. The prevalent response was positive: that drawing the same options would make a difference, referring implicitly to the potential reinterpretations of a hand drawn proposal and new insights. Interaction with various media is therefore very important.

Although student Sb1 was a confident (2D) CAAD user, she referred to hand drawing as being more conceptual and thought that hand drawing in either platform (digital or sketches) was important to design synthesis and analysis:

> *"Yeah, it probably would. That would probably be more conceptual if they were not on CAAD. I mean in my sketch book, I have lots of sketches and, I use CAAD drawings to sketch over so I've got lots of analytical little drawings like this." (Sb1).*

In spite of the prevalent agreement, Sb2 suggested one reason why these options should be different. If there were changes or modifications to be made, he would make these by hand and move on to CAAD:

> *"They will do, only if it was been modified. If I was going to do changes I would draw them first in hand and then put them into computer." (Sb2).*

Sb3, an enthusiastic CAAD user, merged hand drawing and the representation quality "..*as well, as clear"*, however, this could also be based on whether the student is skilful in hand drawing or not. This student extract also gave an indication of either a CAAD-based process for "*basic mapping ideas"* (massing) or sketching-based process for a detailed level of problem solving (details and interior spaces) rather than an overlapped process.

> *"I do not think they would come out as well. Well, they would not come out as clear, as using the computer. Yeah, I probably will do some, you know, free hand sketching for interior work I think, but for basic mapping ideas, I use the computer. I just find it simpler and easier to use."* (Sb3)

Sb4's response was similar to Sb2 in setting the same condition of whether changes had been suggested or not but added that starting from scratch would be more useful. However, this was perceived as "*going back to something similar*" which recalls the fixed status of the proposed design.

> *"If we were to redraw what we have already then probably not. In that case, you already know what we have. If we were to draw from the start, yeah I*

think it probably would make a difference. And the design probably would be different, but now that we've already got the one plan in our heads I don't think that if we went back again.. always find that you can end up going back to something similar because you've done the work for it." (Sb4).

The students were asked whether the options that were reviewed would direct their work for the next stage. Sb1's extract confirmed two propositions: the tutors' role in directing the student and the review as a rectification point.

"I'm not sure yet, because as I said I've not actually spoken to them (tutors) properly. I've gone and been working in the studio spaces, until today." (Sb1).

Sb2's extract suggests that the student had been asked for further exploration of the proposed options (2D CAAD blocks):

"Yeah, no I will keep the (drawn) blocks.. useful. But I may, I may not arrive at this conclusion again but …another or a modified one." (Sb2).

Sb3's extract suggests that after the review, the student felt uncertain about the next step or the route, hence the review acted as another starting point:

"Not quite, not quite yet. They have given me an idea of what can and cannot be done on the site, but not really a specific route as to what I am going to go down. No (direction), not yet, not yet." (Sb3).

Sb4's extract suggests that he was the most certain amongst the other interviewees and the review acted as a continuing development:

"I hope so kind … well hopefully I develop the master plan over the coming few weeks". (Sb4).

"I don't think so. I think it was more just kind of when you're creating a space it's just kind of you just suddenly come up on it or find it. I suppose it's like walking around a real site you just find that area that's kind of the point where you think it would be nice." (Sb4).

The interaction between the students and tools and their ability to be critical towards the used tool also depends on the level of skill in using this tool and how confident they feel in interacting with a tool in the academic context of the studio. If the skill is available, then interaction will take place as a result the student's ability to be critical will mature. Every interaction had features; these features were identified as a result of the student reflection -contextualised reflection– that was framed by the project model and the acquired skills after at least four years of education. These features had an effect on the student's design behaviour in using a certain tool with respect to the context and the need.

7.3.8 Reflection

In both phases, common themes emerged regarding the benefits of asking the students to be reflective on the processes they experienced. At the end of each interview, the students were asked whether the ongoing discussion was useful in helping them rethink and revise their work. Many students were positive about "reflection-on-action" and it has helped their thinking by recalling the whole process. However, they did not want to revise the strategy mainly because of time constraints rather than other factors that may influence their studio work. Quoting student Sa3:

> "*Probably, probably to look at it, not to revise the strategy but to just understand what I have done or just to go back and think, because we don't really have the time to go back and think because we need to keep going all the time so*." (S3).

The extract above highlights the design situation when being thrown into a design problem context. Students do not have the time to be reflective about their work and understanding as it seems a time-related issue rather than a way of doing things; they reflect on their work during pin-ups and crits. However, there is no time left for amendments and changes as the timeframe becomes tighter with studio work progress.

Finally, the second phase interviews ended with asking whether these questions were useful in rethinking or modifying the presented work. Most students were enthusiastic about the questions that were employed as a form of "reflection-on-action and process" and thought that it had helped them their thinking by recalling the whole process rather than revising their work. As such, the resulting impression was useful in the following ways: Sb1 analysed her drawings and was able to identify why the questions asked were meaningful to her work and process. That is the student consciously learned the characteristics of a (CAAD) drawing that were valid for designing and design situations.

> *"Yeah, you've made me look into my own drawings. So yeah, I think they have, yeah definitely. It's (question) made me think about it."(*Sb1).

Sb2 explained how such questions could elicit a critical evaluation of the process that he had been through:

> "*Yeah, they've helped me to, to think about question why you're doing something and whether it's helpful or not*."(Sb2).

Sb3 specified the representations that he had produced using SketchUp (tool) , which been criticised (and were somehow rejected) by the reviewers for using CAAD early in the process. The questions enlightened the content of the representations rather than the obtained and conveyed impression by reflecting on the used tool with respect to how and why it was useful. However, Sb3 maintained the tool state as a "*good tool to be used at the moment"* but recognised other opportunities implicitly in saying he would "*go back to the hand sketches for my interior views",* which implies that he had recognised that there are other conceptual opportunities within the space of the exciting building:

> *"Yeah, no I think so. Yeah, it is clearer in my head again that it is, you know, it is a good tool [referring to SketchUp] to be used at the moment. So, yeah, maybe go back to the hand sketches for my interior views and things. But, yeah, yeah, no, it has been good."(Sb3)*

Sb4 specified the best point in time for reflection. This point was when learning and doing were still relatively fresh in his mind in order to be able to critically evaluate by identifying answers for what and how questions.

> *"It's good to, kind of, remember what you've been doing and stuff, yeah. At the moment it's all quite fresh in my head, because I can think back, kind of, see all of this stuff, but yeah I think it's doing us good, kind of knowing that and remembering what you've done and how you've done it." (Sb4).*

7.3.9 Summary

With time, students became more confident in identifying the design problems and concepts. The level of confidence was higher than the first phase as the students were more immersed in the design problems and the design concepts. Even in the case of the fourth student who worked on the blank site of the new town, he was able to identify that setting problems was part of the design situation. This could be handled through setting constraints and criteria for the potential scenarios.

Design exploration has been classified as active or passive depending on the method of exploration. It is either active by being physically in the design situation (site visit), to engage the senses, or in passive exploration through 2D visual images. However, active exploration is directly related to the level of familiarity, and how the student becomes familiar with the design situation (a collection of problems that make the context of the current state of the given project or brief).

At the second phase, the choice of design media became student-centred but at the same time, it was also centred on the features of the required representations for this phase work. Through the project model, two features were set for CAAD representations: the level of abstraction (formation and massing), and the size of the printed representations. These were found to be useful in influencing student practices in a cooperative interaction between 2D CAAD and sketching. The smaller CAAD drawings enabled a comparison, a kind of comparative thinking between the two, and needed less time to be drawn hence more time could be spent on conception. This helped in establishing a relationship between creating sketches and being analytical, as the small size presentation made the interplay between sketching and CAAD drawings possible, where the student's level of abstraction is considering the whole site (level 0) through physical engagement in levels 1 and 2. That is to say, through smaller drawings, the students were inclined to engage in a holistic approach to the design problem (conception) whether the medium was a sketch or CAAD representation.

At this stage, a separation between the different software programs emerged, especially between AutoCAD and SketchUp. The students differentiated AutoCAD from SketchUp, the former being for (2D) drawing and the latter for 3D exploration. Most of the students who were interested in form generation and form studies have reported that SketchUp is used for concept design exploration. The degree of idea development was also based on CAAD programs' separation. Frequently, AutoCAD concorded with "working drawings" and SketchUp concorded with conceptual exploration or 3D exploration. This reflects the different nature of the software in the students' eyes as they are able to identify specific tools for particular tasks.

Different software helped to create different worlds and in employing different software programs the student became familiar with what medium to use and when to use it, therefore the variation in CAAD software programs is also important. To be able to fully realise CAAD limits and potentials, students need long practical engagement.

Other features were identified that were related to CAAD practices within the studio model. Some of the project model requirements brought indirect engagement with CAAD drawing, for example poor quality CAAD drawings that were given to the students instigated a requirement for practical work by conducting surveys to assess the exact dimensions (parameters) of the existing building on which the new works is based.

A number of the conceptual themes that interested some of the students initiated CAAD practices, however, the student did not have the right skills to explore such issues. This finding suggested that when the required skill is not available, students tend to find an alternative way that complies with their capacity. This could be good or bad: good in terms of forcing the student with such traditional context to use and practice CAAD skills which may encourage learning but bad if the required skill (missing) will provoke other means of design exploration. It is obvious that students would use any material that was available to construct their design world and explore conceptual formations even if it was Lego building blocks.

Time was also mentioned at this point of reflection, as one constraint for idea variation. However, time was estimated as part of the design process, the design situation, and the contradictory implications of uncertainty and variation of the conceptual phase of designing.

One example found how media can bridge the student's lack of understanding and recognition. The tutors suggested collage as a method of relating what had been learned from the precedent study in the first phase. The work done by the students in the first phase of the studio project was not enough to make the conceptual connection between the precedents study and the new site design. Another intervening medium was needed to bridge the gap of understanding, therefore, the tutors' directed the students to an aiding approach (collage) through traditional means. It is useful to understand this. The project model suggested traditional means stepped into the process and inverted its procedural direction again to paper based means. The tutors' knowledge and practices have ignored or overcome the recent advances in digital urbanism. From the students' responses, the studio has been conceived as an important medium for inspiration by allowing access to other people's ideas and explorations.

This analysis showed that the studio review (crit) and the involved representations acted as a diversion point in the student's design process. This was based entirely on design representations impacting on the reviewers and their appraisal and reflection. The representations might be accepted or rejected depending on the extent of traditional perspective held by the reviewers. This process is perceived as another design start or as a continuum of rectification. The discussion in this section suggests that review and criticism and the evolved representations act as a diversion point in the student's design process that is based entirely on the review panel and what this panel may decide. In a way, it is seen as another start or a continuum of rectification.

Design media flow and variation is one of the key characteristics of the studio model. A common theme of design media in the present study was the use of sketches, CAAD and Photoshop.

CAAD's role and purposes at the middle of the studio project can be summarised as follows:

1- to provide a means for representing students' proposals. These proposals were based on representing sketches as part of the designed building.
2- to speed up the process of re-representation between sketchy representation to CAAD.
3- to balance individuals' skills and preferences of seeing their designs, and make the required changes.
4- to substitute sketchy expressions whenever students' needed accuracy and scale.
5- to complement other tools' features by setting smaller representations.
6- to explore certain visual aspects through computer based strategies, for example copy and paste, rotate and move which may reveal unexpected visual formations by the immediate feedback.

CAAD's purposes at this stage were influenced by the conceptual progress of the student alongside the project requirements. Moreover, CAAD utility in the studio context would primarily serve students' perspective (need) and its applicability for design exploration. There are no opportunities for gaining new skills within the project model, thus, superficial representation practices had been observed.

7.4 Third Point of Reflection

The third point of reflection is at the end of the studio design process and just after the final presentation (hand in). In general, the responses from this point of reflection indicated a higher-level of certainty compared to the earlier two points of reflection, where the students were asked to elaborate on their projects in more detail with a holistic view. They were asked by questionnaire to reflect on their design strategy and process (how did they go about the design problem) in written forms. The third set of questions (set 3), in Appendix C-3 p. 365, was employed.

Table 7-6 the case study used mixed methods of studio reflection.

Points of Reflection	Project structure	Methods	No. of responses	Gender	Mean Age
point three	Semester one, at the third critical event of studio reviews	Question set 3.	18 Sc responses	11 female 7 male	23

The analysis of the third point consists of eighteen responses (questionnaires) , Table 7-6, who participated voluntarily. The responses were coded as Sc1, Sc2, Sc3,…-Sc18. The findings are presented in the following sections:

7.4.1 Design media process

At the end of the first semester project (last point of reflection), students were asked to arrange the media types that were employed through the first semester project in succession (e.g. drawing then modelling then CAAD modelling, etc). All respondents arranged the used media linearly, suggesting three sequential patterns. These patterns are:

1- Hand drawing (sketching), AutoCAD (drawing), Photoshop (presentation), and then Modelling (physical).
2- Photography and Photo-montage (survey), Modelling (physical), Hand Drawing (design), AutoCAD, and then Photoshop (presentation).

3- AutoCAD (drawing), Photoshop (presentation), and then SketchUp (3D exploration).

The first pattern is the most frequent among responses (13 respondents) and the third pattern is the least common (1 respondent), that is CAAD based. Within these patterns, hand drawing was the most frequently used media in the two common patterns 1 and 2 whilst 3D CAAD was mentioned only twice, once within the first pattern, and another in the third pattern, which supports the role that CAAD had during the project.

The resulting patterns indicate the conceptual development of students' design process. Based on these patterns, it is clear how the students' level of uncertainty is changing through the produced artefacts and representations (from 2D to 3D and from sketching to physical modelling). The digital model seems to bridge the two extremes. In general, students started from a free, unrestricted medium, followed by an accurate and quick way to view and check their designs, for example CAAD, and then achieved a good representational quality by using an editing software.

Moreover, it suggests that students were focused on one media type at a certain time in the process, and that media type was mainly assigned or requested by the project model, while the sub processes of self communication were not stated in the responses. In general, students' media preferences were dependent upon the following needs:

1. to try different ideas quickly.
2. to express ideas.
3. to make changes quickly and ensue accuracy.
4. to develop (CAAD prints or scanned drawings) further by hand.
5. to present professional looking ideas.

Hand drawing was used for the following features: speed, fluidity, freedom, cost and spontaneity. Typical quotes illustrate hand drawing purposes:

> "*It is the quickest way to represent and record your thoughts and ideas.*" (Sc2).
>
> "*Because I find it easier to develop ideas*." (Sc3).
>
> "*We used sketching for design as you can produce a lot quickly and can jot down rough ideas and do not have to be accurate with your sizes etc*." (Sc14).

Drawing was also preferred for the master planning project, as it was also described as easier to solve problems. This suggests that drawing in its basic form is used frequently to handle studio projects at any level of complexity or size, implicitly referring to production. One student states:

> *"Because master planning is such a large scale project, it is easier to solve problems and to design proposals in sketch form.*" (Sc4).

The second most frequent tool used by the students was CAAD (most of the students meant AutoCAD). Students (6 respondents) reported that CAAD was frequently used for the following features: speed, ease, and accuracy. The following quote highlights the benefits of CAAD for (2D) drawing purposes:

> *"We also used CAAD a lot to develop our hand drawings into accurate plans which we then used as a basis for more design by hand"* (Sc14).

> "*to draw up elevations of the towns used as case studies as a diagrammatic study and were also used by the model making group to make the town models."* (Sc15).

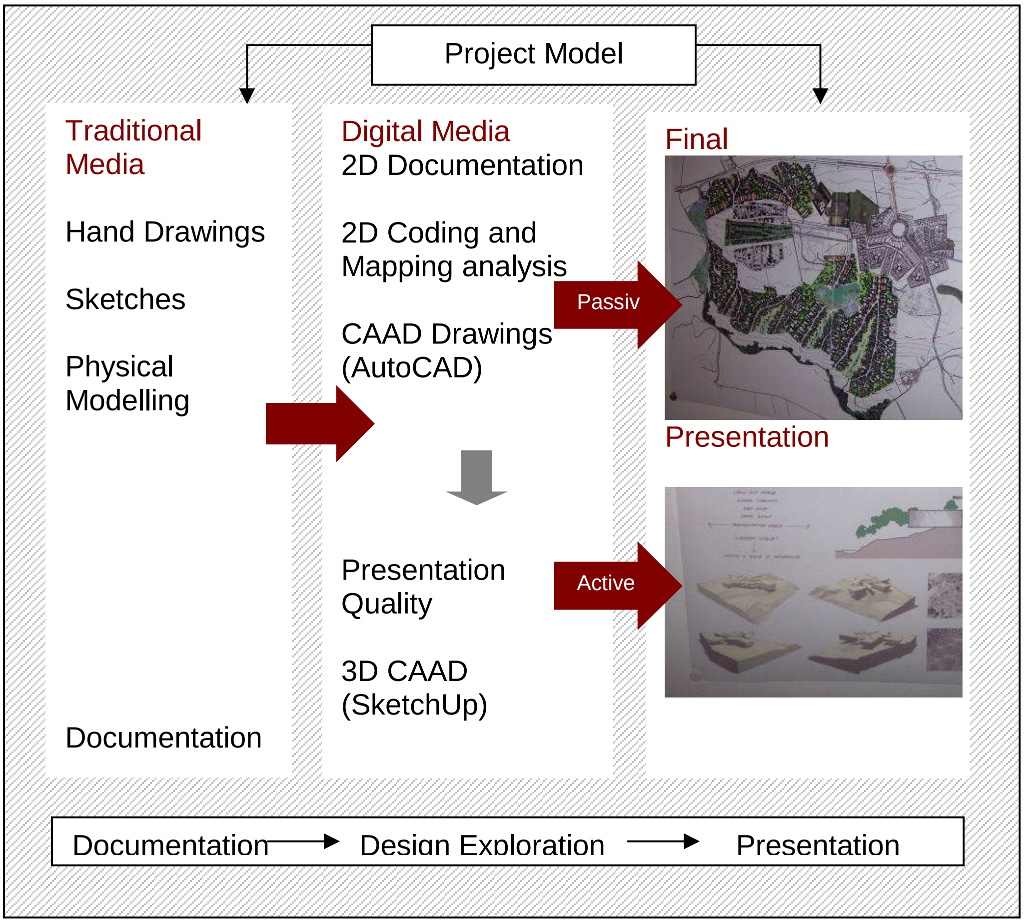


Figure 7-15 Media types and flow for the first semester project.

Students regularly start their design processes by hand drawing and sketching (Figure 7-15), and then move into CAAD for checking the areas and sizes, or making modifications. Photoshop was the least frequently used media, mainly because “*it has good presentation abilities*.”(Sc10). SketchUp came last, because of the project model’s higher level of abstraction (precedent schematic evaluation and problem identification). One student states that: *“because semester one (project) required us to investigate and develop a solution rather than finding ultimate design solution*” (Sc12). This was also apparent at the second point of reflection. One example was provided by case Sb3 analysis in section 7.3.5.

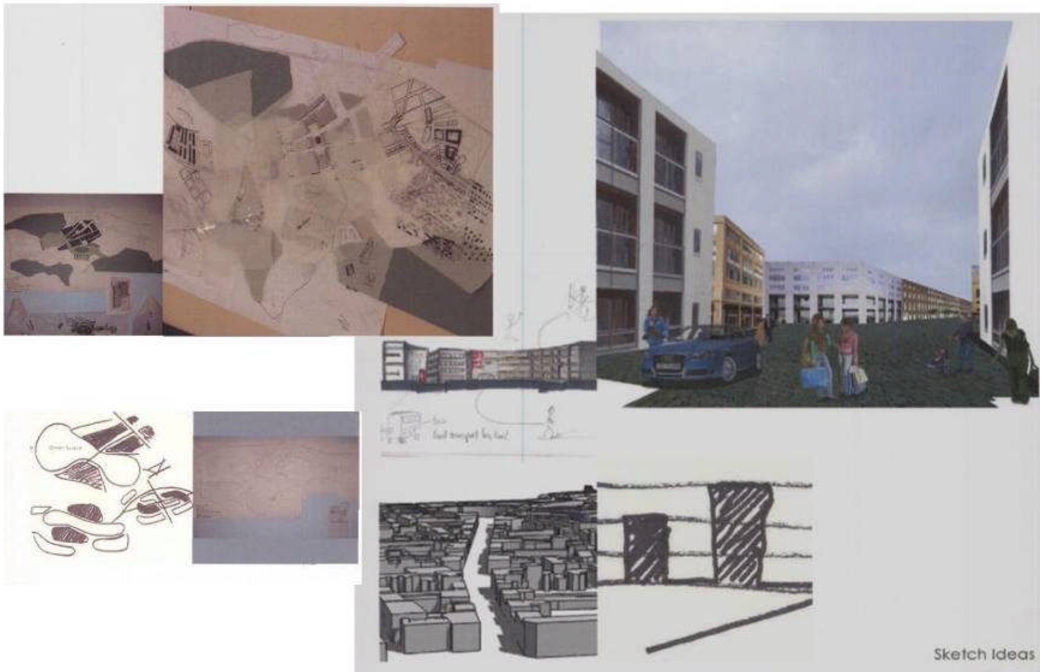


Figure 7-16 Design media variation at the studio.

Using a variety of media was useful in terms of collaboration with other students (15 responses). This practical theme confirms what had been noted in the first point interviews in section 7. 2. 6. It was also useful for finding an interesting visual formation to inspire thoughts (13 responses), speeding up the systematic evaluation of the study (13 responses) and looking at more than one conceptual possibility of the project (12 responses). In addition, students felt that using various media was less useful for looking at more than one conceptual aspect of the project (9 responses), prompting design creativity (9 responses), and overcoming the design task uncertainty (*ambiguity*) (6 responses).

7.4.2 Design media advantages

The features of design media at the three points of reflection were common. The most frequent feature of the used tool was *being quick in doing the required task.* The amount of time a student spent doing a task is a criterion to use a certain tool, whether the tool is CAAD-based or sketching-based. Hand drawing and CAAD were both described by students as quick. This feature is common with concept design and student terminology, that is to say other studio studies referred to this feature as well. However, accurate drawings need more time to be accomplished, therefore, accuracy and speed are contradictory. Although this might be true, it seems that CAAD provides a complementary platform to achieve both at the same time: checking their conceptual design early provides better grounds to accept or reject these propositions, hence either way providing more time for concept design. As a result, using CAAD alongside other tools allows students the extra time to engage with concept design on a regular basis.

7.4.3 Influences on media selection

It has been demonstrated by the analysis of the first and second interviews that media choice is accompanied by a learning strategy, which pertains to the project model rather than any other potential influences. However, at the third point of reflection, students' responses suggested that this was influenced mostly by personal skills (15 responses) and the type of study undertaken (14 responses). The former result had also been identified in the second point reflection, and the latter result was also identified from what was gained from the first point of reflection, in relation to the observed effect on the strategies used in the studio. The students also rated these features of the studio context as being less influential from the previous two; the approach to study various architectural themes (13 responses) and project characteristics (e.g. complexity, size, surroundings, others) (12 responses). In addition to these, students had rated the influence of studio tutors, that is encouraged by the tutor(s) (6 responses) with a minor influence, however, many instances were observed of tutors' influential role on student's progress in general, and on media choice in particular. Other features of the project model, for example the systematic evaluation of students study, and accessibility and affordability, (each was ranked by 3 responses only), were seen as having less influence on students' choice of media.

7.4.4 CAAD and the process

The students were later asked this question: if they had not been able to use CAAD during the project, what effect would it have had on their design processes? Five students did not think it would have affected their design process if they were not able to use CAAD during the project, whilst seven students thought it would affect their design processes and two students thought it may or may not affect the design process.

Of those students who agreed that it would affect their work; the consequence identified was in concordance with time required to finish the work, quality achieved and hardship in producing the physical models. Typical time-related responses were:

> *"Yes. It would have taken much longer to achieve the same finished quality" (Sc1).*
>
> *"Yes, it's very hard to be accurate by hand when creating a site plan where there are no straight base lines, and there is hardly any orthographic drawing equipment about now." (Sc2).*
>
> *"Yes. A model would be much harder if we did not have accurate drawings which we could use as a template." (Sc6).*
>
> *"Yes, because I am not good in sketches - probably look appealing and convincing enough." (Sc17).*
>
> *"Certain tasks may have taken longer. Only one hardcopy, mistakes would not have been so easily changed." (Sc16).*
>
> *"It would have been more difficult to access plans of case studies and would have been less precise; the final presentation would have been less appealing." (Sc14).*

Other students who did not agree thought that it would not change the process that they went through. This highlights the strategic thinking subpart of the process because CAAD's role in the project model was not part of strategic learning, indicating that the process would not be changed if CAAD was not part of it. Typical extracts were:

> *"No I feel I would still have used the same design process." (Sc10).*
>
> *"I don't think it would have produced a major difference as the design was a piecemeal of different towns based on tracing of towns already in existence." (Sc12).*
>
> *"No, my designs tend to come from thought and sketching rather than characteristics of a software program." (Sc13).*

“As CAAD was not used in the design process then no. I could maybe speculate that using CAAD would have limited the design process as the area to master plan was larger than anything ever tackled, meaning we were learning and experimenting as we went along and using CAAD you do this is too precise a design tool and would have taken too long” (Sc15).

This suggests a passive role for CAAD in design methodology and context, and at the same time, an active role that has taken place in the routine subpart of design, where students push forward the process by means of time and speed.

7.4.5 CAAD impact on design aspects

Using CAAD affected the way students interacted with studio tools and context. Nearly half of the respondents (7) felt that using CAAD would not restrict their thinking in any way as *“all round useful*” (Sc14). Other respondents identified specific aspects they would be forced to think about during working with CAAD. These aspects were in the form of problems that were revealed as a result of CAAD’s accuracy, for example scale, sizes, dimensions and regulations. Typical extracts were:

“Does the design physically work” (Sc18).

“Yes probably. Problems come to light that possibly weren't thought about during sketch proposals.” (Sc9).

One student related scale to recognition of the scheme as it enabled the connection between what is being studied and the real scale, the size of the designed scheme.

“As soon as it was in CAAD and scale was added we were aware just how large the scheme was!” (Sc7).

In addition to accuracy, CAAD medium implies visualisation of design in *context: “the urban fabric and master plan of the area.” (Sc6)* and automated effects that CAAD can provide such as shadow studies and massing: *“Design aspects that might be really helpful is the sun orientation and shadows of the building” (Sc17).* Consequently, even when CAAD had forced the students to work on specific design aspects, the students’ reflection did not reveal a negative impact on their thinking process. In general, it showed that working with scale is needed to contextualise the imprecise and loose phase of concept design into a more coherent understanding of the proposed solution. This would be looked at in the protocol study.

At the end of the project, more than half of the responses (10) agreed that CAAD (visualisation) helps to *develop* new ideas, students' extracts mentioned words like axis, possibilities, modelling, understanding while eight students disagreed with these findings. Typical extracts were:

> *"yes: Easy to set up axis etc. and I can quickly try different possibilities". (Sc4).*

> *"yes: Sometimes it can help if you are having difficulty in visualising shapes using a 3D program such as SketchUp can help with understanding." (Sc9).*

> *"yes: 3D CAAD modelling provides a very quick way to try out various spatial configurations and volumes. It can give a quick visual representation, however I still feel it is necessary to then make a hand built model to truly understand the spaces." (Sc10).*

7.4.6 CAAD Experience

At the end of semester one project, and at the final phase of the structured reflection, the students were asked what tasks the CAAD experience had influenced alongside the design process. The students felt that the CAAD experience had more impact on the following two tasks: *the way students communicate design* (16 responses), and *the way they document solutions* (11 responses). The observation that both tasks *communicate* and document was evident in many of the responses at this stage. There was less impact on the *way they think about design* (7 responses) and *the way they solve design problems* (6 responses) and a minor impact was noted on *the way they make design decisions* (2 responses).

The students felt that their design ideas changed when they started working with CAAD. Thus the change occurred as a result of CAAD's capabilities as a medium rather than a change of the conceptual insight per se.

> *"Normally problems are discovered as a result of using CAAD so the changes do develop"(Sc1).*

> *"Yes. Not the overall concept but you start to get more into detailed design and may realize sizes do not fit and things need to be changed. However when making these changes I prefer to print out the design and go over it in red pencil."(Sc15)*

> *"Normally problems are discovered as a result of using CAAD so the changes do develop"(Sc1)*

The cyclical processes of evaluation and analysis could be traced but in CAAD the characteristics of framework of scale, preciseness and realism were achieved.

The relationship between the CAAD experience and potential change in ideas was based on what was being seen in the CAAD platform as a more constrained environment (medium) for design exploration. This is characterised by scale, accuracy, preciseness, practicality and detail. Typical quotations from the respondents were:

> *"Probably less free. By using CAAD I am less likely to explore other ideas in a conceptual manner." (Sc16)*
>
> *"It maybe makes you think a little more about issues that had never arisen during sketching and hand drawing."(Sc4)*
>
> *"Not the overall concept but you start to get more into detailed design and may realise sizes don't fit and things need to be changed. However when making these changes I prefer to print out the design and go over it in red pencil."(Sc15)*

In addition, other views presented showed that students would now use CAAD as a medium for drawing up, though previous planning had been done through sketching. Typical quotations from the respondents were:

> *"No I usually have the overall design planned through sketches and models before I start drawing up in CAAD."(*Sc2)
>
> *"No, the idea is being drawn up"(Sc8)*

However, there was no mention of new insights into design or that the change in medium had influenced the way they perceived design. Even when they agreed that changes may occur, they tended to do it by hand:

> *"However when making these changes I prefer to print out the design and go over it in red pencil."(Sc15)*

What motivates students to change the media they are working with is the limitations of the tool and potentials in a certain representational context. Students' responses revealed an awareness of the potential benefits of using a certain tool at a certain time, and were mainly presentational. Typical extracts were:

> *"When another media will be more useful: accuracy, visual appeal." Sc2*
>
> *"The need to further design specific sizes or a more accurate representation of the design or for presentation purposes." Sc15*

7.4.7 Final presentation

With regard to the earlier points of data collection, the presentational criteria had slightly changed. At the end of the project, the conveyed message was characterised as a certain and final scenario. This was to identify which presentational criteria were important within the specific projects the students mentioned, some of which reflected conceptual aspects. The most frequently mentioned presentation criteria were: *clear* (5 responses), *detailed* (4 responses), *accurate* (3 responses) and *readable* (1 response). The selected tool to achieve these was CAAD. Typical responses were:

> *"An accurate description of our scheme texture and realistic features of landscape and lifestyle."* (Sc7).

> *"A clear and accurate representation of our master plan."* (Sc16).

It is interesting to identify what effect the final presentation had on the students' thinking process or the process of conceptual development in terms of process continuity and decision-making. Most of the students (12 responses) found that the final presentation was important from three different perspectives. The first viewed the final presentation (hand in) as a focal point of critique and diversion:

> *"The final presentation acted as the fulcrum to which all the potential scenarios converged to the final outcome."* (Sc2).

> *"Important as any other critique"* (Sc6).

The second viewed the result (tentative scenario) of this semester work as a continuum to the subsequent project. Typical views expressed were:

> *"It marked the end of the master planning and allowed us to develop sites for future projects."* (Sc1).

> *"Very important, as it set up my initial thoughts and ideas, which I am currently developing in more detail."* (Sc9).

However, producing the final presentation was also important as part of this continuum for conveying content and meaning hence the concept design intent. This suggests that moving from the higher level of abstraction was valued by the students at this stage, which was also favoured in the first semester work.

However, the third perspective concerned the relationship between the final presentation and the development of potential scenarios. It had been seen as speeding up decision-making and making the required changes:

> *"We changed our final presentation a lot in the final week, so we probably left a lot that should potentially be developed in more detail." (Sc16*)

"It was just an expression of what we had been doing all term although it did make us make final decisions" (Sc14)

"*Really important-because if you fail to put your message it cannot be conveyed and the viewer will not understand what you want to do."(Sc17)*

Whilst other participating students (5 responses) did not find it important for the development of their potential scenarios as they related it with the product per se, it did affect their thinking:

"*The final presentation was made after the potential scenarios were developed." (Sc15)*

The final presentation was, therefore, important to the students in stopping the design process by making decisions more speedily and enabling them to proceed mentally to the next step, conveying the final message of the process, and finally receiving the reviewers' appraisal.

7.4.8 Presentation potential changes

The students were asked if they would like to change anything in the final presentation, bearing in mind that they had answered this question after the final review and the reviewers' appraisal and had also been exposed to other student presentations. Only a few students (5 respondents) thought that they would not change anything in their presentation, taking into perspective its final status. However, most of the respondents (13 respondents) identified at least one aspect that they would like to change. These aspects varied from presentational to design-focused (on the level of design conception), that is related to the content rather than the appearance. Both may be considered as an integral part of the conveyed message. Additional criteria related to reviewers' satisfaction and understanding are also important at this stage.

Three respondents identified presentational criterion, for example tone, colour and realistic as areas they would change. Typical extracts were:

*"The 'blackness' of the buildings compared to the overall presentation - they stand out a lot" (*Sc1*)*

*"Some of the colours I felt our design was a bit dull, but it was a group work so I could not change it."(*Sc8*)*

Other students (5 respondents) wanted to add more information, either written, or visual such as 3D models and realistic representations. Typical quotes were:

“More information about ideas. Perhaps a more realistic representation of our scheme.” (Sc 16.)

“Ours was a bit rushed as it changed a lot after our crit the week before, I would like to make it more cohesive”(Sc14)

Other students (6 respondents) mentioned aspects that were design-based rather than presentational as the quotes below illustrate:

“The design outcome of the final presentation has now changed, but this is just the natural process of design progress and I'm sure it'll change again before the end.” (Sc2)

“The presentation was ok - it was the content that was lacking! I would probably add more of the AutoCAD analysis and mapping, and possibly a less collaged technique with lighter buildings.” (Sc11)

From the above extracts, the potential changes are mostly concerned with the presentational criteria on two levels: the first concerns the appearance, e.g. colour and tone, and the second level concerns the conveyed message and information about the design approach (process), the relevant details and the project description as well as the level of detail when students mentioned other criteria, such as, “*3D visuals”, “realistic”, “CAAD analysis and mapping”.*

7.4.9 The Design Methodology (the project model)

The majority of students (15) felt that it would be useful to mix physical and digital models compared to using physical modelling only. Utilising both types of modelling was recognised as a better way to explore “*the model*” further in terms of digital physical modelling, exploring other materials, visualisation of spaces, and because digital models are more useful for the latter phases of the project. Typical extracts of the respondents who agreed with this point were:

“Not to mix together but perhaps utilise both” (Sc3)

“Yes as we produced these for our final solution and it would have been good to compare these solutions.”(Sc1)

“it would be good to be given to explore another material sometimes you can see the texture or tectonic of the whole town.” (Sc17)

“It would add further visualisations of spaces and materials and will be useful at the later stages of the design presentation.” (Sc2).

The physical models can be an active part of the process, and, especially when the move to CAAD has been made, this will “*be useful at the later stages of the* *design presentation*" (Sc4) which implies the continuity of using the created models whether digital or physical. It was noticed that physical modelling is a very time-consuming process that was neglected after the precedent studies phase was completed.

The time that was spent in modelling was a factor that affected student's willingness to model physically or digitally: "*Yes, although it would be easier and quicker to produce all of the model digitally*." (Sc9). Another student thought *"If the appropriate technology (mix both) was available, (then) maybe.*"(Sc5).

Another perspective (4 responses) appraised physical modelling as the most appropriate when it was contextualised in the project model and the relevant studies of the precedent. The type therefore became a contextualised preference that suited the student need:

> *"3D digital models can be good for designing as they are quicker to produce. However the wooden models were of existing townscapes and I don't believe that it would be useful to produce them digitally."(Sc11)*
>
> *"Not in this instance as they were purely precedents"(Sc14)*
>
> *"Possibly but I do not think you would get the same effect from a digital model."* (Sc7).
>
> *"I prefer physical models but I can see how 3D models can provide an attention gabbing "selling" image." (Sc16).*

However, digital modelling was in line with "designing" that is representing a modified situation rather than a real situation of a precedent, and in terms of the time factor as it was both quick and easy. Regarding the idea of contextualised preference, one student did not agree with utilising both, as physical modelling provided her with an "inaccurate sense" of the created 3D model:

> *"No. all you would get from the wooden model is an inaccurate sense of mass. You would get no sense of material, character, density of openings, types of buildings or building uses" (Sc15).*

In the light of the earlier phases of data, the first phase interviews suggest that 3D modelling was the only way for the students to understand the precedent, as they had to pay a lot of attention to the details, sizes and volumes. However, this suggests a diverse perspective on how to choose the right tool for the right task, especially when the tool could take a very long time to use compared with other possible tools.

7.4.10 Learning CAAD

Most of the participating students (14 responses) did not feel that the methods applied through the project were applied in a new way, apart from three students (3/18). Two students responded by specifying familiar presentational techniques that were applied for the purpose of this year's design methodology but were combined into CAAD, digital scanning and Photoshop. Typical responses were:

> "*Used AutoCAD to make colourful diagrammatic/analytical drawings"* (Sc11).

> "*We used quite a lot of hand drawings to present our master plan. We scanned in hand drawings and then coloured them in Photoshop."* (Sc16).

The third student had specified the design methodology as a familiar process which was applied in a new way but on a different level of inquiry i.e. on a big scale (the master planning) thus indicating increased project complexity:

> "*The whole process felt as if it were done in a new way as I was carrying out the process in the same way but applying it to a master-planning project, which is different in character to any other project I have ever done. However, I also had to learn about master planning by myself from scratch and incorporate all the rules into the design process too."* (Sc15).

The scale of the project was the one feature that students mainly found new to their knowledge base and practice. However, this was not achieved using CAAD tools but with a traditional tool; collage.

With respect to learning new CAAD design/presentation techniques, nearly half (8 responses) of the respondents stated that they did not learn any new CAAD technique during the first semester project (11 weeks project). Of the majority who did not learn new CAAD techniques, two students mentioned that they did learn new techniques but these were identified as "*few*" and a "*couple*" of techniques developed through AutoCAD and SketchUp. Moreover, two participating students reported that they had learnt a new CAAD package whilst working on the semester's project, for example, Photoshop and ArchiCAD, based on the project model feature of group work or a presentational need.

> *"I have learnt a few additional things about AutoCAD and SketchUp through working in a group."(Sc4)*

> *"I learnt a couple of new Photoshop commands and techniques." (Sc14).*

> *"Learnt to use Photoshop during this project, by using the program and using others knowledge." (Sc5).*

"Yes working on ArchiCAD so that I can produce better digital 3D image."(Sc17).

On the other hand, through the traditional level of media engagement and interaction that was enhanced by the studio tutor, two design techniques were learned and described as new in the context of the project:

"*Collaging street scapes to produce a master plan was a new concept as were the mapping processes of the first half of the semester (Precedent Study).*" (Sc11).

However, the responses revealed that CAAD learning had different criteria than simply gaining theoretical knowledge. As such, CAAD learning had implied other objectives, such as:

- To learn "*better and quicker processes"* (Sc16). Learning not only implies knowing the operational/procedural moves (using the right command to do something) but also knowing how to do it fast.
- To learn by "*picking up new things"* (Sc6) by continued use.
- To learn the newer version by updating the software and therefore a newer way of doing things.
- To learn more about existing techniques while using them.

The above points are illustrated in the following quotes:

"Not that I can think but possibly as you are often learning better and quicker processes with CAAD and Photoshop." (Sc16)

"using CAAD programs is a continuous learning tool - you are always picking up new things, new tools." (Sc6).

"upgraded to AutoCAD 06 and its new techniques" (Sc3).

"Used existing techniques, but learned about these techniques".(Sc13).

Besides these objectives, using CAAD for a long time seems the most significant factor in CAAD learning and skilfulness; *"I have used CAAD for a very long time (10 years) and have learnt a lot from working on placement."* (Sc1). In addition to the learning context "*on placement*" and "*through working in a group*" (Sc4), learning has been "*mainly through working alongside different students" (*Sc14). These extracts confirmed what was noted as a result of the pre-studio project survey.

The most notable trait that resulted from this case study was the practical distance between contemporary CAAD practices in architectural design and architectural education. Within the participating students, there was no mention of a new method that was learnt in the project as an alternative to applying familiar methods and processes in a new way, which was noted by one of the participating students.

In the case of using CAAD as part of the students' process of media transition and interaction, all the identified methods were presentational. They consisted of editing, colouring and adding text to see what the proposal would *look* like. As a result, the methods that were used to create students' compositions were very similar to the methods that were noted in the main questionnaire survey, at the very start of this study (before 11 weeks of project-based practice). No method based on conceptual design was commented on by the students and this reflects CAAD's traditional utility of the design studio.

However, after presentation, another term came to the fore: *expression.* To emphasise the dual status of the created drawings, it had been stated that it was important within conception to see what the students' ideas were going to look like. Expression and viewing designs was not something that was left for the end phase of the design process. It was something that accompanied the thinking process which might be based on the interplay between hand drawing and CAAD. The dualism of a drawing action is taking shape between sketching and CAAD rather than within the same medium, that is hand drawing. A distinction should therefore be made between the presentation criteria of an educational (academic) design process and a real (professional) design process, to reflect on the differences.

7.4.11 Terminology

The students' terminology and meaning explicitly referred to their understanding of the design problem and the design situation. This provides two issues that can be traced within the emergent findings. There were two instances of students interpreting problem as a difficulty that was faced during task fulfilment rather than an issue which needed to be identified in respect to the design context of that task. However, when asked the question again, conceptual issues were identified within their reflections. This also revealed a relationship between design meaning with the students feeling that they are researching rather than designing. (So the holistic approach and the way the project was introduced to them was important and could affect these two issues: meaning and understanding).

> *"Site and it just kind of a daunting task just to kind of see it for the first time and just how big it is."* (Sc13).

The students' description of their projects at the final phase brought the terminology of the project model to the surface with a variety of perspectives. This variety was reflected in the language the students used when describing their projects. Differences in wording suggested different conceptual perspectives, regarding what they were talking about, the level of the design phase, and the development of their design thoughts. The conceptual perspectives emphasised either the design problem or the design solution. However, other students focused on the design intent (goal or aim) by explaining why it was done (objectives). Moreover, some of them used more than one conceptual theme to do so. The students' responses also regarded different levels of enquiry, for example house town centre, master plan, sense of place, distinctive architecture and other design issues like zero heating, and exploration of the present status.

7.5 Summary

Most responses were contextualised in the project model of studio, through which learning took place. This was revealed in a process of "*knowing-in-action*" (Schön 1987) that is based on the student way of thinking. This process was evident in the student's reflection and practices, which was also related to the expected work of the subsequent phases. Students' recognition of the precedent was conveyed through an ensemble of analytical design methodologies (as a new place and a precedent), as this was part of the precedent study and also part of students' learning experience and gained knowledge.

As had been noted in the analysis of the first phase, the interaction between students, tools and student's analytical ability was predominantly controlled by the project model, for example precedents and 3D physical modelling. Whereas in the second stage the interaction was controlled by student's personal preferences and analytical expertise with regard to the design situation, that is the interplay between sketching and CAAD programs. Moreover, in the third phase of reflection the students were asked to state the media used through the whole process, and this is where they revealed that CAAD was the prevalent media after the early phases of the design process before either modelling or Photoshop. All the participants (18) stated they used media in a linear pattern of transition, which usually started from sketching or hand drawing, passing through CAAD and ending with either Photoshop or physical modelling. As a result of the stated transitions, the most frequently stated/used media were sketching or drawing, CAAD (AutoCAD) and Photoshop, respectively.

The role of CAAD at the studio on the macro level of design activity was defined as passive and mostly concerned with CAAD's presentational aspects. Few practices were documented that were based on concept design exploration. As a result, the studio process impact was greater than the socio-cultural impact of CAAD on studio practices, however, some design practices were directed towards digital media.

In fact, the studio project model is the most important context for CAAD integration and skills development, but still resistant to change or integration. The question needs to be asked; when is studio going to embrace CAAD as a knowledge base of design methods and processes, which is constrained currently with project model, tutors' attitude toward CAAD, and previous knowledge and practices?

Within these patterns, hand drawing was the most frequently media used in the common two patterns 1 and 2 whilst 3D CAAD was rarely mentioned. Nearer the end of the studio project, the resulting patterns indicate the conceptual development of students' design process. Based on these patterns, it is clear how the students' level of uncertainty is changing through the produced artefacts and representations (from 2D to 3D and from sketching to physical modelling). The digital model seems to bridge the two extremes. In general, students changed the media characteristics from a free, unrestricted medium, followed by an accurate and quick way to view and check their designs.

Using a variety of media was reported as useful in terms of collaboration with other students. It was also useful for finding an interesting visual formation to inspire thoughts and speed up the systematic evaluation of the study and look at more than one conceptual possibility of the project.

It was demonstrated by the analysis of the first and second interviews that media choice is accompanied by a learning strategy, which pertains to the project model rather than any other potential influences. However, at the third point of reflection, students' responses suggested that this was influenced mostly by personal skills and the type of study undertaken. This highlights the strategic subpart of the process because CAAD's role in the project model was not part of strategic learning, indicating that the process would not be changed if CAAD was not part of it.

With respect to learning new CAAD design/presentation techniques, most of the respondents stated that they did not learn any new CAAD technique during the first semester project (11 weeks project).

The students felt that their design ideas changed when they started working with CAAD. Thus the change occurred as a result of CAAD's capabilities as a medium rather than a change of the conceptual insight per se. They also reported, even when CAAD had forced the students to work on specific design aspects, the students' reflection did not reveal a negative impact on their thinking process. In general, it showed that working with scale is needed to contextualise the imprecise and loose phase of concept design into a more coherent understanding of the proposed solution. This would be looked at in the protocol study.

In the following chapter, the focus group study provides an extensive inquiry into this year cohort's experience and CAAD teaching methods to probe students' preconceptions in relation to present, past and future experiences, and to see whether these can be changed and how.

8 Study Three: Focus Group

This chapter presents the findings of the third and final stage of the case study, highlighted in Figure 8-1. The purpose of this discussion was to raise some of the emergent themes from the earlier stages of the case study (survey and studio reflection). This stage was at the end of the second semester project, with participants reflecting on their CAAD practices within the context of their projects of the two semesters.

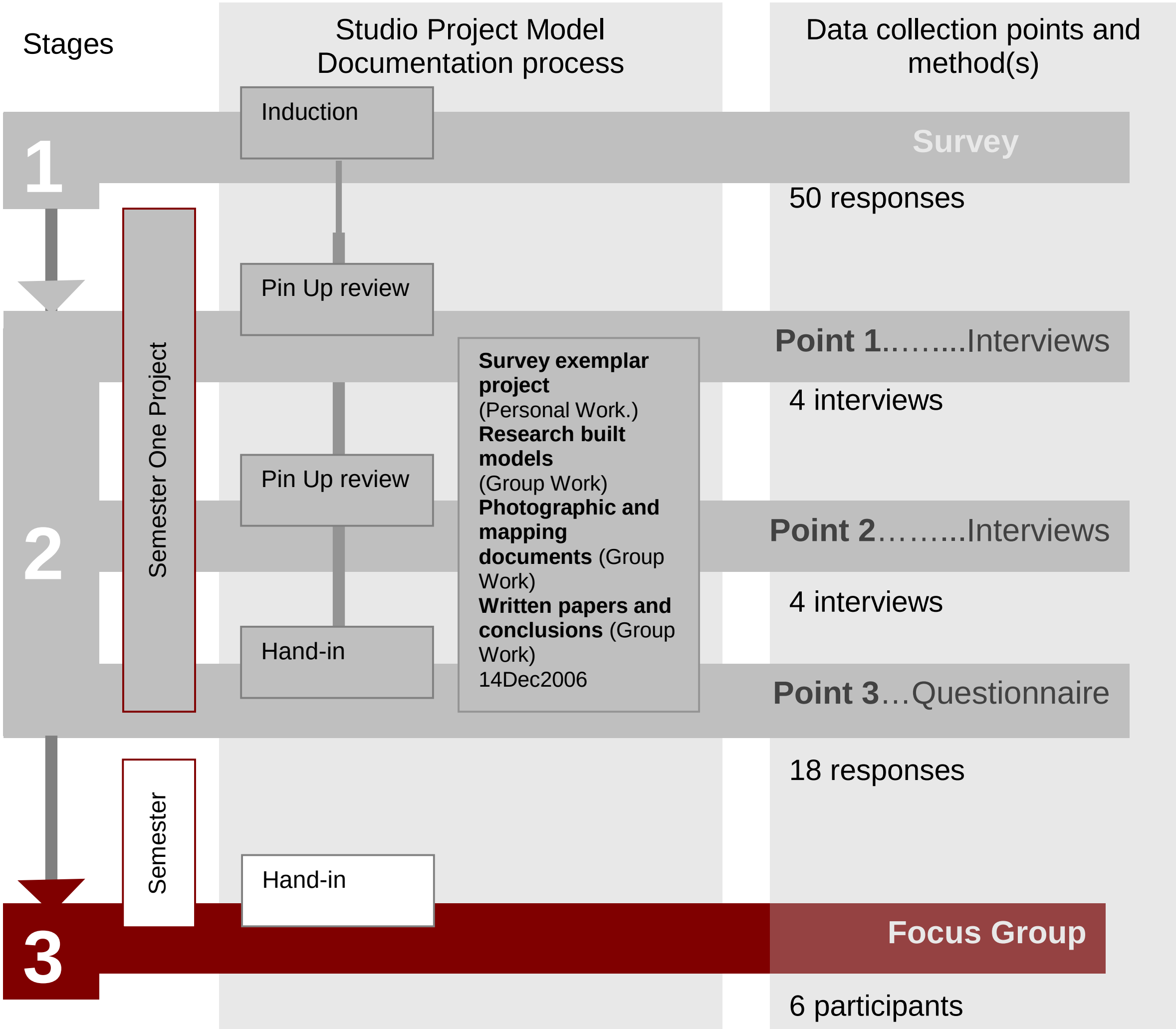


Figure 8-1 the third stage of case study analysis using focus group.

Both semesters projects complemented each other but the second semester project was focused on a lower level of abstraction and smaller scale.

8.1 Analysis

Although focus group analysis includes many theoretical approaches, it is recognised that the required enlightenment is dependent on pre-analytical factors such as "*how the study is framed, who is selected* (willing) *to participate, the ability to provide interpretations instead of just findings, and the nature of questions*" (Krueger, 1998 p.13). The objectives of this stage are based on Krueger's (1998) focus group analytical strategy to "*seek answers*" (Krueger, 1998 p.14). The objectives are:

- *to challenge the emergent themes from the earlier stages of the case study, survey and studio reflection, for example CAAD utility themes at the early phases of architectural design, the academic project model, CAAD speeds up the process.*

- *to challenge what was arisen but never probed properly and still suspected, for example CAAD term and meaning with respect to CAAD programs variation. Impact on visual thinking.*

- *to see if the discussion would change final students' perspective towards computer aided design rather than computer aided drafting.*

- *to discuss some of the recent trends in CAAD learning and teaching.*

8.1.1 Participants description

The participants were six final year students from cohort 06-07 who attended the discussion voluntarily. The discussion lasted approximately one hour and twenty minutes. Participants IDs are: S1 (female), S2 (Male), S3 (female), S4 (female), S5 (male) and S6 (female). A diagram is provided in Figure 8-2, to show the seating arrangements (decided by the student) and their relation to the slide show, the moderator and the camera position. The camera was used to obtain a better quality recording of the discussion and to provide a reference point to the guide used. The focus group slides are provided in Appendix C-4, p. 368.

Table 8-1 Focus group participants.

Case study stage	Project structure	Methods	No. of participants	Gender	Chapter
Stage 3	Semester two, after the final presentation	Focus group, Guide, Appendix C-4.	6 participants	4 females + 2 males	Ch 8

Krueger's (1998 p.74-75) analysis and reporting strategies of focus group data suggest that reporting numbers (or percentages) of a focus group analysis should be used with caution. This is because the focus group method is underpinned by qualitative research methods and procedures, so using numbers may indicate that the results may be generalised to a population. Bearing in mind the study purpose of probing further on the findings of the earlier points of reflection to gain a complete understanding of the context, descriptive phrases were chosen over numbers such as, *few*, *some*, *several* and *prevalent*. This is arguably imprecise and any form of quantifying up responses should be avoided.

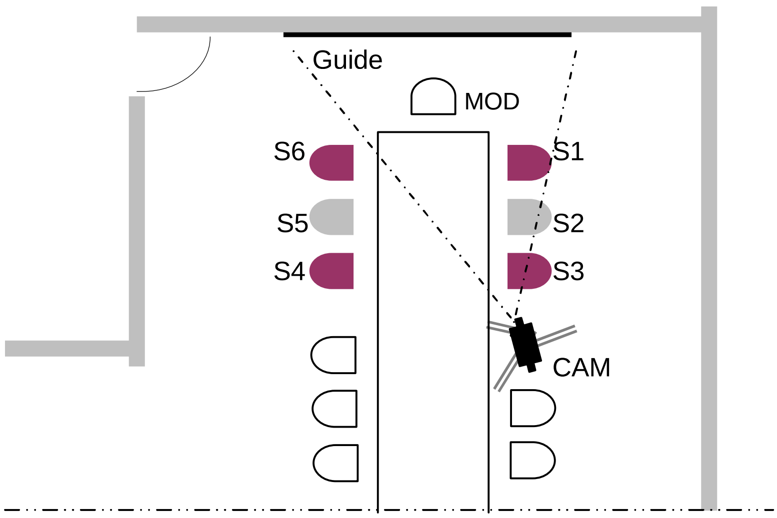


Figure 8-2 The focus group seating arrangement, coded by the participants gender (light grey for male and dark plum for female students) and ID.

8.2 Findings

This study objective was to provide reflection on the role of professional systems within the traditional context of final year studio, shedding light on specific aspects of CAAD learning and teaching. Students' discussion considered the following topics: CAAD terminology, concept design, design process, CAAD characteristics, CAAD learning and teaching and professional practices. These were disclosed and contextualised based on students' past and present experiences, as well as future expectations and concerns. Past experience was concerned with early motives to learn CAAD, teaching methods and project model. Present experience was concerned with what is gained after finishing the project, and futures perspective on CAAD as part of their professional life.

8.2.1 CAAD as a term

The term CAAD in the present study is based on what are so-called professional systems: professional, educational and innovative (Achten 1996), described previously in section 3.1.2. These systems are off-the-shelf software programs, developed by standard software companies, and primarily selected by the institution's pedagogical approach. In addition, the term CAAD in the literature is treated as an inclusive term of all CAAD systems that may be used for the architectural design process.

One frequent observation among the three points of reflection was students' (interviewees') tendency to specify CAAD or SketchUp when they were asked CAAD-oriented questions. Based on this outcome, all students agreed that when the term CAAD or CAD is mentioned, the first package they would think of is the AutoCAD software program. Accordingly, the term CAAD is not inclusive or generic from students' point of view.

As the debate continued they revealed two aspects of this tendency. Firstly students tend to separate what is termed as CAAD into three separate packages: AutoCAD, SketchUp and Photoshop. Although Photoshop was not mentioned in the guide questions and is regarded as an editing software program rather than CAAD software, it was highlighted by the students as one of the professional systems.

In one of the student comparisons, another student specified that AutoCAD and SketchUp is for design and Photoshop for presentation, although the separation of CAAD packages is agreed by all the students, she cites implicitly that she is aware that Photoshop is not one of CAAD's packages *"but Photoshop is kind like after you've done the design, put through Photoshop".* (S3). On the other hand, there is an indication to the non-conceptual status of the design "*after you've done the design*", as Photoshop is used for presentation and graphical complementarity, including an editing software program that reflects a tendency toward personalisation.

All participants agreed that when CAAD is mentioned they associate this with the most used CAAD package AutoCAD (no mention of ArchiCAD, although it has been taught in parallel, and it is also a CAD compound term). In this regard, student S2 agreed that CAAD means AutoCAD initially, but because he has used different design software programs (CAAD knowledgeable student) in the past, he thinks that Photoshop is another useful program. This reflects another form of AutoCAD dominance in architectural education.

In brief, the discussion suggests three things: 1) defining the term CAD or CAAD as a meaning was based on a practical context in relation to the way it was used by students during their university education, 2) introducing CAAD in a detached manner from its historical evolvement and philosophies, and 3) to reflect on the differences between different CAAD software programs such as AutoCAD and SketchUp, which are totally different in the way they work.

8.2.2 CAAD's role in concept design

Another facet of the term CAAD that was discussed, was whether the letter D in CAAD would stand for design or drafting. Students stated that drawing and designing could not be separated, as they have "*always been a mixture*" (S3). In other words, one would lead to the other. The other aspect of this claim is drawing (sketching) and the use of a computer, and how both should "*run parallel*" (S3). As well as using the term Computer Aided Drafting, this also raised the term sketching in the discussion and debate on how it is used in relation to CAAD.

Participants’ extracts brought about three different terms: “never”, “ever” and “always”. According to content analysis (Straus and Corbin 1998 p.19), these terms reflect two different situations under two different conditions. In this respect, the student had determined the situation of “*ever*” when she cited using computer for designing as the *only* medium, the only medium was the condition for this to be so. She also had a similar situation (never) when she cited the importance of using both mediums and not to use one medium at the expense of the other. As both are important, one for “*sketching things*” and the other for checking what has been sketched against CAAD accuracy to see if it actually works, accordingly changes are made. Quoting S3:

> *“I think it is a mixture it is always been a mixture. I do not think I will ever be able to design anything fully on computer. I will always have to go back to sketching things out.” (S3).*

However, the student has contradicted the previously mentioned situations with the other term “*always*,” she stated:

> *“However, there's always a point that I get to in a sketch where I have to go onto computer aided design to get the accuracy and it works, but then I may change something during that process but I will never have one without the other. So there's always going be things that run parallel for me.” (S3).*

The situation of “*always*” has been identified in two instances where the student cited the following conditions: that design and drawing is a mixture of both, that is, the necessity of drawing as an act of designing but also, the changing status of being in one medium and deciding to move to another medium “*go back to sketch*” and “*go onto computer aided design to get the accuracy*. This shows a need to change the medium type (characteristics) upon the students’ critical assessment of what is needed for design problem solving.

The discussion evolved around the question of whether using CAAD has helped them in developing their design concept(s). Several students strongly felt that CAAD is not for conceptual design, as concept “*always comes from your head and from little sketches*” (S6) and “*But the first kind of ideas is here (pointing to her head) and in your hands and then kind of CAAD helps you a lot to check the concept (design) if it works*.”(S4). As opposed to CAAD where the concept is taken to be checked rather than re-created, although one can see how that would change in the following paragraph. It is apparent that every time sketch(ing) is mentioned in the discussion, CAAD's accuracy and practical applicability is pointed out.

> *"No, I do not think I use CAAD for conceptual design, I think that always comes from your head and from little sketches and things. CAAD is more like if you have to design of a staircase and to make sure it fits and make sure you have enough headroom and stuff like that. Although you might use, like, SketchUp for some of those. Is the only thing that I can think of" (*S6*).*

Moreover, one student (S3) claimed that using CAAD early may "*hinder concept as well*" by making the concept fit too early and giving it the "*preciseness*" (S6) where ideas might be lost. There were also views which confirmed that CAAD is "*too detailed for concepts*" (S6). This would affect students' level of abstraction, where they would shift their focus from considering the concept as a whole to be concerned with "*half a millimetre*" (S6), shifting students' attention to check dimensions and other aspects of CAAD characteristics.

One student (S4) who pointed out the difficulties of sketching with a mouse compared to the natural way of scribbling. Implicitly, this claim shows how students imitate habitual praxis with a totally different environment, CAAD.

> *"It is still kind of, you know, sketch with a mouse it is difficult, to scribble something quickly. That is like more natural I think, yes, and then use CAAD whatever you put into that, well AutoCAD or whatsoever." (*S4*).*

After pointing out the notion of design evolution through drawing by the moderator, the students were more open minded to claim that CAAD aids concept helped "*realisation* "or "*making you realise your concept but not the concept itself*" (S1). Concept realisation includes from their perspective "*what does* (concept) *really look like*" and that is attainable "*only from seeing that (concept) you can make changes*" (S1). As seeing enables identifying weaknesses or faults in a concept and how to make corrections by changing the initial state of design to another state (transformation). This realisation became possible with CAAD accuracy "*you find out that your pre-design propositions, actually does not work- to correct pre-design propositions*!" and to check what you have perceived as right and then it appeared wrong (size, dimension, relation). Other students stated that what is really helpful in CAAD is printing (having a hard copy of the design site plan) and drawing over it by hand to make changes and mark out things "*that gives you space to design*", print out a scaled site, map or plan, or even a grid (as part of the design methodology they are applying). In addition, this discussion was an elaborated version for the next statement of "*it's not really using CAAD for design; (it) is more like using it as a tool to get a template for design*."

In summary, the above discussion suggests that students are aware of design media variation, which helps them see things for the first time and make changes. It shows also an awareness of what is useful to be done by hand and what is useful to be done by CAAD (being critical). Developing such awareness would enhance time management, as well as speeding up the thinking process. Consequently more time would be allocated for design solving rather than drawing accurately. Students agreed that switching between two different media and representations could work in parallel not at the expense of the other.

However, participants' views changed when another package was mentioned. On the contrary, SketchUp was brought into the discussion as a more useful tool for first concepts, and in parallel to the following features, seeing quite accurately very quickly, test how this building-forms and masses. S2 stated:

> *"SketchUp is more useful for first concept. Mainly because it's really just about getting things, you can see something quite accurately- on the screen very quickly and you can then start to test how this is building, you know, forms, masses and things up rather than a sort of details."* (S2).

Few students suggested that SketchUp characteristics could be more suitable for design exploration than AutoCAD (CAD). This suggests that there is a point just after the concept and just before moving to CAAD when SketchUp is more suitable for seeing and testing the first (early) design concept(s) for its third dimensional aspects, for example *shapes of the building, forms and angles*. From the students' perspective, obviously SketchUp was defined as a 3D package as opposed to (Auto)CAD[1] for being "*too detailed for concepts."* (S6) Thus, SketchUp had been positioned in-between conception and CAAD, somehow bridging the gap.

> *"I used it quite a lot. We used it to get the shapes of buildings and work out angles between them-and things alike. I would say a 3D package like SketchUp, which is just dead quick and dead easy to use, and probably maybe not the actual concept but you know, just the next stage of the concept."* (S2).

[1] When a student mention CAAD when a distinction is important between the two main discussed programs then either it is written like Auto(CAD) or (Auto)CAD.

"That one stage after concept only almost before CAAD, you know in between may be." (S3).

To conclude, these insights suggest that the cyclic process of design may overtake sketch/hand drawing to CAAD but within CAAD, it may also occur through more than one software program. That is to say, if AutoCAD was used as the only CAAD program then the cyclic process would consist of two stages of media exploration, conceptual sketching and CAAD. However, this may change when various programs (SketchUp and AutoCAD) are applied, then the cyclic process would include three stages of exploration: conceptual sketching, SketchUp (3D exploration) and AutoCAD. Apparently, this would imply other differences in the mode of exploration whether 2D or 3D.

8.2.3 Representations characteristics

CAAD's role as a representation was connected to the combination of CAAD software programs, as the latter parts of the discussion had revealed that most of the students regarded Photoshop as necessary; this was based on the claim that CAAD "*has no character*" (S1), "*It's quite depressing*" (S6), and "*soulless*" (S4) and they consider Photoshop as a complement for (Auto)CAAD's representations. Student (S6) stated:

"You print things out and they just look so soulless, just a collection of lines, whereas doing it, even doing it by hand and pencil, you know at least it had a character, which CAAD doesn't really have, until you put it into Photoshop and worked at a bit and come back to it" (S4).

Another student stated that this may be changed and gave an example of a way to overcome such restriction or automation in AutoCAD by "*setting it up*" (S5) to accommodate a more individual expression. S5 stated:

"I can always automatically just draw or maybe just draw in one colour, and I can almost work out on the screen how it looks before I print it. So I suppose in that way you can get a bit of character about it. It is a lot easier if you can put a headline where you need it and stuff, and to strictly straight away you can (able to) see it." (S5).

It is perhaps worth mentioning here that student (S5) likes prefers AutoCAD and had been using it for 14 years – a long time compared to other group participants who used CAAD for the last 4-6 years, so practice gave him this practical flexibility.

Uncertainty of a design or a conceptual proposition is strengthened by externalising ideas or what is being thought of on paper to test its feasibility as well as to reflect on it. With that level of uncertainty students could not externalise with CAAD because is a demanding medium for information, accuracy and speed. Moreover, working with CAAD does not change the students' sketching habits and tendencies, as jotting down how to draw or what to draw is still an essential task even if they are mainly working with CAAD. This could be interpreted in two ways: the first pertains to the nature of the drawing acts in CAAD as opposed to hand drawing. The approach to each drawing is different - drawing in CAAD needs planning before acting and in sketching acting is spontaneous and natural (as S4 has previously mentioned). Thus, drawing in CAAD is multiplex process compared to sketching. The second way to interpret the same observation pertains to working memory load.

In general, design (conceptual design) is a mentally demanding process that may be affected by any parallel process that occurs at the same time. Since working memory is limited, the approach required to draw shapes or diagrams in CAAD may increase working memory load. One of the students could not remember what she wanted to draw or what to use for drawing it, "*I forget half the way through it's so immersed in which commands to use and things*" (S3). Moreover, other students confirmed this view by saying that even if they are copying some kind of a construction detail they would draw it first on paper, where a note of the observed detail will be kept for further use, or as a reminder and even for understanding through drawing or writing. These aspects combined made students keen to explore what they want to draw by hand first. Typical extracts were:

> *"Like even when I am working with CAAD, and I have a bit of a paper beside me I tend to sketch things on paper -design on the paper, and then draw it on CAAD because otherwise I can not remember how I am supposed to do it, or I forget halfway through because it is so immerse in which commands to use and things."* (S6).
>
> *"Even with 3D as well, the dimensions and all that."* (S1).
>
> *"What would it look like in sections?"* (S1).

These extracts provide an indication that CAAD has a different role to other tools in the design process, and supports the idea that these differences are appreciated upon the characteristics of each. One significant difference is that CAAD drawing needs preparation, thus hand drawing may provide a template or plan for CAAD procedural steps but at the same time the act of drawing may provide a better understanding of what has been drawn, that is looking or seeing what is there is not enough to understand the structure so students use drawing. As one student said:

> *"For some reason this is all visualisation for me, even the work construction details. I did very often, even if I am looking at a text book have it to draw on CAAD, I will still have to step and draw what I am thinking of"* (S3).

This suggests that before using CAAD drawing what the student is going to draw in CAAD is applicable in both 2D and 3D modes of drawing. This supports the view of CAAD drawing bearing on working memory, and how understanding is obtained through drawing. Therefore, hand drawing is necessary whether the purpose was pre-planning for CAAD drawing, understanding or thinking, as hand drawing serves various purposes.

Throughout the discussion, the students mentioned presentational criteria such as realistic, photorealistic and "*not only CAAD*." It was observed that students referred to CAAD drawing often as professional and realistic or photorealistic, which appear to be considered as merits of such drawings or visualisations. These presentation aspects emphasised the representational quality, ability to produce such quality and probably its direct relation to professional practice. However, when they were asked about how important it was for them to present their designs realistically, they were more inclined to set a divergent system of presentation that was an abstract system of colouring. Quoting S5:

> *"But even then, it doesn't have to be a photorealistic render, which could be a kind of cartoon kind of colours system, blue sky grey for slate rather than the actual proper photo kind of reflection, grass and stuff."* (S5).

An abstract system is referred to implicitly by the suggested criterion as opposed to realistic render, which is presentational. Concurrently, the term used imparted another purpose of using realistic presentations: "*It does not have to be that kind of understanding."* (S5), this reflects on representations understanding of the non-design community and representation readability. Quoting S5:

> *"I do not think it is, because we can understand, like, kind of the tutor should be able to understand it. A qualified junior architect should be able to*

understand their drawings and things like that. I think we can understand as well because we are kind of similar level." (S5).

The criteria were mentioned in two contexts, the first context was communication and understanding in relation to whom it is conveyed. The second context was the appearance of whether it is sketchy or defined.

Participants considered the automated effect of CAAD operations on the resulting representations as if they were done for them passively, which reflects implicit concerns of identity and authorship of concept design and how architectural design is an individual effort that needs to have the designer's character instead of what CAAD is presenting. Typical extracts were:

> *"if just feels like a bit sketchy and stuff, you know, you can project more of what you want to see in it, and if it's already been done for you, you think oh no."* (S5).
>
> *"For presentation purposes that I prefer to see a little less, like you know how in Photoshop you can put your quick work on and do anything on it and stretch whatever and stuff. But I prefer the thought of it more, architectural a little bit more sketchy and, you know, leave something to the imagination."(*S1).
>
> *"I think also if it is rendered up, it's quicker to read and it's easier to read ....architects who could view their elevations but the line drawings are actually drawn up, you don't have to concentrate on the lines and be quicker."(*S6).

Participants' discussion suggested that students preferred *sketchy* representations and related their preference to *imagination*, which also reflects on the exact character of CAAD representations giving the impression of a design rather than of a conceptual design.

8.2.4 Tutors' role

Students agreed that the tutor's attitude towards CAAD use (AutoCAD in particular), influenced students' attitudes, hence practices as they had been told not to use CAAD early, and "*try to keep yourself away from (Auto)CAD"* (S3) or *"Please stay away from AutoCAD*." (S4). On the one hand, such negative attitudes were mostly based on the relationship between CAAD and concept design, thinking that CAAD would affect concepts in two ways: internal (imagery and interpretation) and external (form and other). Other extracts on CAAD's potential impact on internal externalisation were:

"..to keep an idea, an image, and a design in your head." (S3).

"I mean before you kind of have your concept, otherwise you end up with having squares or something with a very rigid form, because it's easy, you just sit there and draw." (S4).

Some of the extracts were on the external level of CAAD representations, where a contradiction between the positive appraisal of photorealistic representations appear to bias tutors judgment or appraisal, which in return had an influence on concept design assessment (given grade) of the same work. A division between what is tangible (representation quality) and the conceptual content of the same representation was noticed in the following extracts:

"Then you get the grade or you think you have lost it. You have gone and focused on this little bits where you have kind can, what about this space and that space."(S5).

"Yeah, it is quite difficult. Actually, I think a lot of architecture on this university course is trying to second-guess what your tutors want to see."(S6).

"Yeah, kind of the concepts lost in the details." (S6).

On the other hand, another aspect of tutors' negative attitude relates to tutors' set of CAAD skills and knowledge. Participants claimed that the majority of tutors could not use CAAD in their design practices and they do not know how to use it, however tutors admired students' visualisations and appraised them. One student stated that:

"I think some lecturers think that if you see something that is completely kind of photorealistic and done, well, they think it in two ways: they think while it is amazing and kind of wish they could do it....and well you have lost the concept" (S5).

Another aspect noticed was the tutors' expectations towards students' CAAD skills. At this stage of architectural education (MArch) tutors had high expectations of their students' level of CAAD skills, which seemed to not always correlate with the actual level of CAAD skills or what had been taught in previous years. Typical extracts were:

"They expect to be the level of the rest of the class."(S1).

"Yes, they expect you to do things that you have been; you have never been taught to do."(S3).

"..and they all want to see something different and depending on who you get at the final days... it's kind of, it's just ... I don't think it should be quite like that ... but architecture is subjective they don't stick to their opinion."(S6).

8.2.5 CAAD impact on the design process

All students agreed that if they had not been able to use CAAD during the second semester project, *time* would be influenced in the sense that CAAD provides a faster way to draw, model, make changes and modifications, this description was based on a comparison with hand drawing. Student's S3 and S6 stated:

"*CAAD is so much easier than if you're drawing by hand to make a change*" (S6).

"you really just spend a lot of time while doing your drawing, but then you do not have to spend the same amount of hours doing the same drawing or do all the stuff you can make." (S3).

Another student was more specific in describing drawing in CAAD, as she described the start of a CAAD drawing as time consuming which resonated with other responses, for example drawing by hand before starting CAAD is essential (denotes a planning phase before drawing in CAAD) but when changes were needed it was described as fast. Therefore, CAAD would affect the design process time line as it was cited by the student. Students' description was focused on CAAD practicality in reducing the time required to do the changes, without any other implication like creativity. However, this feature had implicitly influenced the number of changes that a student may undertake, to increase the continuity of the design processes. Students S6 and S2 stated:

"I think if I was drawing it out (by hand) I wouldn't have made as many changes, and my scheme would have been very much the scheme that I came up with three months ago. It might change a little bit but hardly till now." (S6).

"I suppose, yeah, because it's so quick to get that, so making changes, you know, whereas if you didn't have CAAD behind you, your design process has stopped months ago, you know. But because we've got and can use it right to the last minute, you know, changing things, I suppose as such evolving all the time." (S2).

" it's one command that changes the whole drawing."(S6).

Participants made a new connection between the practical aspect of using CAAD within their design process and the tendency to make changes and alterations, as changes were increased significantly. As claimed, CAAD encouraged students to carry out changes and alterations until the last minute before submitting (printing off) their design and the amount of changes made correlate with positive usage of CAAD.

The changes mentioned were focused on dimensions, heights or *"just copy your drawing over and, and alter it again"* (S6). Thus these changes cannot be claimed to make the design process more successful or suggesting conceptual iterations rather mere changes in dimensions or heights.

In opposition to the previous point, one student stated that using CAAD might hinder the project presentation or the time allocated to show the design (spaces). She refers to another level of abstraction, partial perspective. The change in CAAD is emphasised by simple modifications. This could be seen as making easy changes like dimensions, moving one design element a few millimetres or stretching something. This could also have other implications like giving the student a kind of satisfaction that they have worked on their concepts and have made changes but they, in fact, have no conceptual contribution.

> *"Maybe it's also hinders. I find I want to say to myself, stop making changes because you could do so many nice things to show the spaces you have created. Sometimes you just want to be able to put a stop on yourself making changes."* (S3).
>
> *"I think it's not you that's making the changes; it's like when you and they go, "Why did you do that? Why did you do that? Why did you do that? I really think you need to make changes." And you're kind of, like, I've got a week to go."* (S6).

Design media issues of engagement and variation, as discussed previously in section 7.4.2, demonstrated that all respondents referenced media engagement in a linear manner rather than mentioning the media twice in cycles. However, this was clarified through the discussion and all the participating students agreed and acknowledged that the media process of their design process is cyclic and not straight "*I think when an idea exists actually you do go in circles and go back to different stages*." (S6). By saying "*different stages",* the student referred to the interplay between various mediums at the same level of design exploration.

8.2.6 CAAD and problem solving

The students could not make a connection between CAAD and any design aspect where CAAD was helpful in solving a design problem within the context of the two semesters' projects, that is there was no CAAD contextualised implications on design problem solving. Instead, they related CAAD to other projects within the class and globally to digital architecture or what they perceive as such.

Practices observed in the context of the same year's work suggested the following qualities: CAAD was helpful to design what seems "*very difficult to do by hand*" (S6) and needs "*calculations*" (S2). Such as, "*complicated roof - bits that fold*" (S2) "*work out the angles and things*" (P2), "*how, um, everything fits together*" (S2) and "*especially if you've got a room that angles in two directions*." (S6). Angles were mentioned twice (frequency) and by two different students (extensiveness).

In the mean time, few students discussed how CAAD had contributed to make specific buildings feasible on the global level. A typical extract was: "*Yeah, if they did buildings and things like that they have absolutely no chance to create those." (S6).* However, these buildings were characterised by two formal qualities *blocky* and *curved.* Furthermore, they referenced digital architecture in the way they perceive it and how technology in general and CAAD in particular had influenced architecture, quoting S2:

> *"I think in general a lot of the blocky buildings and the curves and things that happen now would not have been possible, you know, twenty years ago. CAAD wasn't then..."* (S2).

Since such features were not available in the students' final designs, they could not contextualise CAAD as such, for example P2 stated:

> *"I do not think my design in particular. I know some people in the class had a complicated roof, bits that fold. CAAD was the only way to do it and calculations, SketchUp as well, it works out the angles and things and how everything fits together."* (S2).

This above extract reflects also on the role that tacit knowledge of design structures play not only in the conceptual design but also in design and its impact on promoting CAAD use. Therefore, promoting CAAD use should be done through gaining both CAAD operation skill and design knowledge. Another student identified the same aspect through skills attainment. In discussing whether a lack of skills hindered CAAD use, after referring to the types of designs that had been produced using CAAD, the students felt that to use CAAD in design is what was needed as well as the operational knowledge in the knowledge of design structures. S3 stated:

> *"So no, it is not the freedom unless you have the skills, even though if I am professional in CAAD you could not get me to create something like that. I think you have to get the knowledge to understand the structure to be able to produce some of these ideas."* (S3).

Therefore, teaching the required skills (operative) of how to operate a tool is not enough to be considered as flexible, instead it should emphasise the created knowledge of the design. Therefore, CAAD had an implicit knowledge of the created structures (designs) along with how it was created which enabled the creation of similar projects or with a similar conceptual quality. It was claimed that design knowledge base was most important aspect. In addition, by this claim another meaning was added to medium flexibility as implicitly, the students acknowledged that CAAD enabled the creation of some of the complex designs (concepts) that are experienced nowadays.

On the contrary, in the current way that students were learning CAAD there is a serious lack of insight into CAAD teaching as a knowledge base. CAAD teaching should create a balance between how and what to design through 2D drawing or 3D manipulation.

> *"I had quite simple structure could not work it out. Until I went to SketchUp and screen that for the whole weekend, evening, just to build a very simple structure to be able then to visualize the whole*." (S3).

> *"So I think that is one aspect probably I would not have understood as well, may be this is another part is understanding as well as designing, that CAAD allows you to be better. I think if I have just created lots of sections and things in 2D you wouldn't get the 3D understanding whereas I did when I put it into SketchUp."* (S3).

> *"Unless you made a model as well, but it takes longer."* (S6).

> *"Yah the speed I was needing that evening so"* (S3).

> *"Yes it gives you a better understanding of the third dimension because it is just in your imagination and even if you draw it, it is flat really it is annoying to work it but it does not it is flat."* (S4).

> *"Your imagination has a 3D picture but it is not 3D yet*." (S3).

Obviously, learning CAAD had evolved under the influence of two effects. The first effect was how CAAD been taught and for what purpose. The second effect was seen after applying the learned expertise within a design context. Moreover, the first effect brought in the tutor's perspective of computer aided drafting and the second effect brought in the student's critical appraisal of needing CAAD for a certain design situation.

8.2.7 Professional practice and CAAD learning

When participants commented on students' preference of learning CAAD as a designing tool while taking a placement (one-year professional practice outside academia), their discussions highlighted that being in an architectural office was the most effective way of engaging effectively in CAAD learning, which made them appreciate CAAD in a more sophisticated way and gain a deeper understanding. Provided that most professional practices had developed and integrated CAAD in a design based context as opposed to academia, taking a placement would provide an opportunity to explore CAAD in a design based context. It was also noted that student's "situatedness" in a professional practice provided an urge to use CAAD, whereby learning is motivated by actually "*doing* (*an) example"*(S6). One student said that one reason was ".. *because you have to (use CAAD)."* (S1). Other extracts were:

> *"You work in placement by doing it, doing example yah because I think we got CAAD courses in the second year, we sat there at desks watching the guy doing CAAD on screen which was quite slow, because the computer was slow, and the guy as well was slow."* (S6).
>
> *"But I think you meant to learn a lot when you working in the office learn shortcuts from AutoCAD and you may know how to do it by clicking a button, click one bit and clicking the next bit, whereas in an office you will take that bit and it will do it for you and then you come back to university and you show that person how did you do it. Probably you would not be taught it at the university."* (S5).

The latter extract (S5) provides an example of how a student may value the practicality of software use, which academia teaching may lack. Therefore, the focus that students had on their experience in architectural offices/placement tended to be about certain differences in the type of exercise, means of interaction, infrastructure, and task practicality. On the contrary, university courses were poor in the manner they were given. The manner can be described as passive in engaging the students, for a number of reasons:

- the students were in their second year of study, when they took the course.

- the setting where the courses were given implied the methods used. In this case, the courses given were described as "*Sitting in a lecture doing CAAD seems quite silly to me." S6*
- the context of the exercise: students mentioned that they were asked to draw an "ashtray" instead of an architecture example or case study, for example Villa Savoye.
- some of the technical problems were also mentioned (computer speed, which was an issue during the time they took their courses around 2000-2002).
- the methods were used in conveying the tutor's instructions created a gap between the instructions given (commands) and application. Typical extracts were:

"You could not see really, what was being pushed." (S3),

"what buttons being pressed you know he goes like press this and do this. You can remember few commands but then you can forget them all also, I think it was very useless." (S6).

All these factors combined influenced students' earlier experiences of CAAD leading to negative attitudes towards CAAD's role in design in general and concept design in particular. However, students claimed that these factors had been minimised in the following years. Typical extracts were:

"Now we do better." (S4).

"Yah in the computer lab now, (CAAD's lab supervisor) goes around." (S3).

"We are actually doing it at the same time" (S2).

This discussion suggests that students were aware of the differences between the two identified conditions within university teaching and the differences between CAAD practices in academia versus architectural practice. Therefore, teaching CAAD should be directly oriented at students' needs and lack of skills. This can be improved through listening to students with appreciation and considering these views and needs by different means of development (workshops, tutorials, CampusMoodle[2]).

[2] CampusMoodle is the virtual environment for Robert Gordon University provides an enhanced set of features to better support students learning and teaching.

On the other hand, participants had concerns regarding rapid technological developments and skills attained through education and the workplace. These concerns varied from continually changing software to workspace technological dependence.

> *"But I do not want to be working for an office in five years, finally be an architect, and then those easy hotshots coming out can design in SketchUp. Oh, so you did that in sketch, that is so old." (S1).*

The following extract indicates that students were concerned about workplace dependency on CAAD and how CAAD practices are totally different to what they had learned during education, quoting S3:

> *"At least we were not a year ahead of that. She had to go into the workplace, where they were all on computers, and start like, she was hit ground zero, you know, you feel like you've got this far as learning masters and you suddenly go into a work and it's a completely different work*."(S3).

As a result, the participants indicated that there was insufficient importance placed on teaching CAAD through their years in academia. They also referred to themselves as a *transitional generation*. Lessons should be learned to overcome the identified gap in the way CAAD is taught, not only at this critical stage of students' preparation and to qualify them for the workplace, but as a systematic process of learning that is based on project size and skills level of CAAD and whether their skills are in 2D or 3D.

A proper assessment should be undertaken for pre-university teaching as well as for exchange students and each year students at the beginning of term to set a holistic vision of how to improve and enhance students' capabilities as part of design capabilities, skills and design theory.

8.2.8 Stages and purpose of learning CAAD

The discussion progressed to highlight how students started learning CAAD and what attracted them in the first place. The responses revealed two starting points for learning CAAD. The first was based on the studied program that pertains to pre-university teaching, when the student felt that she had to do it, quoting S6:

> *"First time I think used CAAD in the university. In (high)school I had to do it because I have been told to do it as we have to produce CAAD drawing, I think that when I started doing it*."(S6).

The second starting point revealed was in relation to CAAD drawing qualities when students felt that they wanted to produce drawings of the same quality. Typical extracts were:

> *"I think I was attracted when we start to see other people drawings in CAAD , oh dear how you did that, you know if you see a good project and a good piece of work you feel a bit inspired to find out how they did it and then go and try learn it yourself."* (S3).

> *"I remember I was in the first year and look at CAAD drawings it looks so professional that they put so much effort in it does look neat at that time you think you should kind of go that way."* (S4).

These two starting points must be used in favour of teaching CAAD. Learning CAAD has been developed practically over a considerable period of time (average of 6 to 8 years) so changing the skill level or learning new skills or packages will not happen in a short period of time. Therefore, learning CAAD needs long practical engagement, obtained through evolutionary, rather than revolutionary processes. Participants' past experiences of learning revealed that this process was biased by many factors; teaching purpose, teaching contexts, student's perspective, tutor's perspective and the teaching methods.

Over time, CAAD learning has gone through three different phases, Figure 8-3. At first students were introduced to CAAD through assignments as part of their course assessment, where they felt they had to do it "*because I've been told to do it*". Then the next phase was when they actually applied what they had learned in their own project and the third phase was when they felt they needed to apply CAAD until it became indispensable.

The first identified condition can be described as passive, since the student had no interest in learning CAAD. The students "*been told to do it*" as part of their studies program to produce drawings, whether it was contextualised in a pre-university program or in the early years (first and second year) of architectural design education. At this stage, the complexity level was low and projects were described as simple, that is one storey, small size structure and single floor.

> *"Then in third year our buildings became more complicated so it became better to use CAAD, or rather than having a single storey building which I think we always had in the first and second year building it is quite single floor small building and structure then you have four floors was obviously large in size try to work that in CAAD makes more sense. And then last year all the angles and things were just messy it kind became indispensable to use it after a while."* (S6).

The second condition of CAAD learning was identified during the latter stages of education and was described as active, since the students had developed a sense of need to use and learn CAAD. The transition from passive to active learning occurred when the students felt that using CAAD "*was better*" and "*made more sense*." (S6). Therefore, students felt that CAAD was necessary because of the increased level of complexity, that is *"complicated building, four floors, large size, angles and things were messy*". (S6).

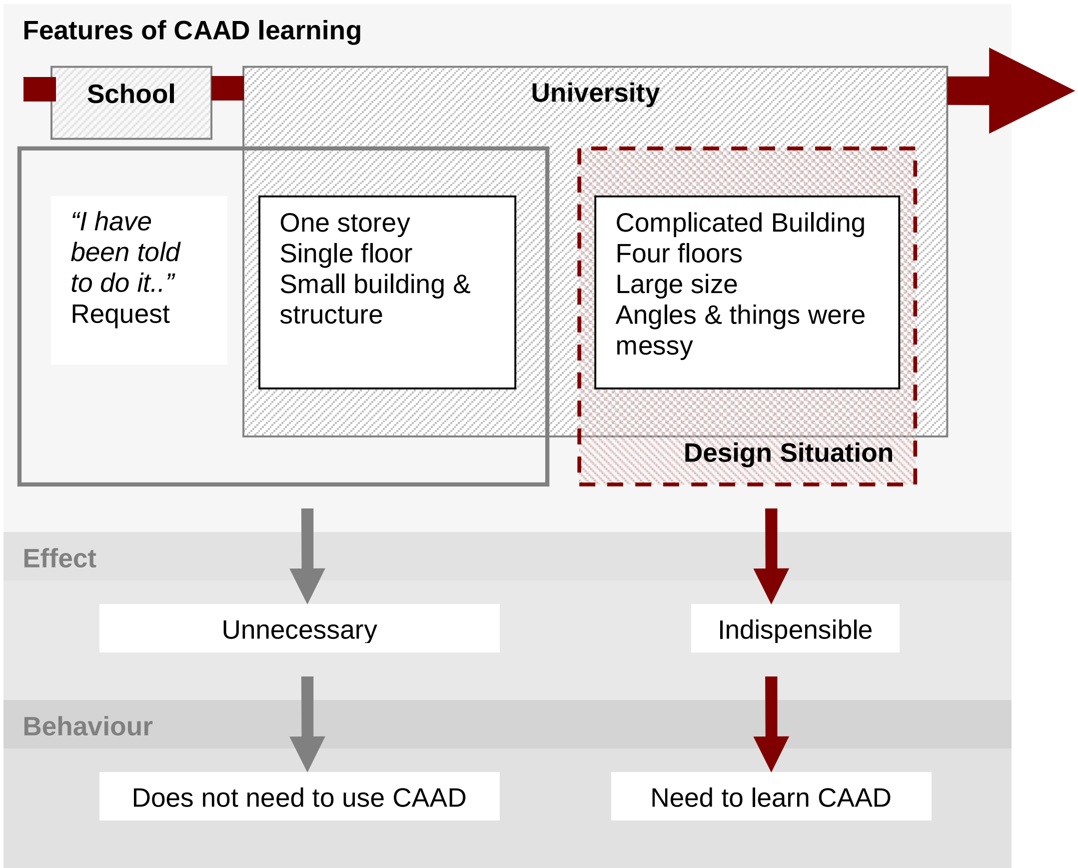


Figure 8-3 A diagram presents features of CAAD learning, propose and effects on CAAD use.

Taking into consideration the effect of the first condition on the students, while CAAD core teaching was passed on to the students (specifying here the first and second year of architectural design education), they regarded CAAD as unnecessary for the immediate context of practice and projects' level of complexity. However, this changed under the second condition when the students needed CAAD to solve and manage the project complexity.

These extracts raised another point; there was no continuum between CAAD pre-university and university teaching. Thus CAAD teaching should look for strategies to bridge the gap between pre-university and university teaching in a continuum: How to overcome the way they perceived CAAD in High Schools and how to create a continuum that university teaching can build on.

However, when a student comes to study architectural design, the curriculum does not challenge these preconceptions enough; on the contrary, the curriculum widens the created gap or attitude. It has to be a continuous process or learning curve. In addition, this suggests that learning CAAD started before learning to design, pre-university learning brings preconceptions that university education has to deal with in a design context and these should be clarified early.

8.2.9 University course

This group had obtained CAAD courses at the second year of their architectural studies (around 2002). Previous methods of teaching were criticised strongly by the students, the courses had commonalty and were criticised for the following points:

- The learning setting and its direct relation to how CAAD had been taught, for example lectures (pre-university teaching), lab (looking at the given instructions without doing it at the same time, which were forgotten).
- The exercise subject was not relevant to design, for example an ashtray, and level of difficulty, "*It was an ashtray and I did not find it useful" (S6).and "it was the most difficult.."* (S3).
- The focus was on software learning rather than design*, for example "how to learn AutoCAD, it was nothing to do with design."*(S4)
- The nature of the exercise/ assignment, for example tracing over, knowing how to do it by yourself, "*an architectural example (a house drawing) it was described as professional"* or *".. were given a really professional drawing"* (S4), and were *"asked ..to figure out how to get this drawing." w*hich they *"struggled for 2 weeks"* (S4) to learn how to do it.

Contrary to the above points, students preferred to learn CAAD by "*doing", as the best way to* make it more *"enjoyable".* Typical extracts were:

> *"Like what would be easier would be more courses teaching to do stuff, and that would probably make it more enjoyable as well because CAAD frustrates me." (S6).*

"Or learning by doing, rather than looking at schemes.." (S1).

Following the same line of discussion, frustration was mentioned in relation to three facets of CAAD use in the studio. The first was mentioned in relation to CAAD learning methods and how to make it more enjoyable (c.f. S6 extract: "*would probably make it more enjoyable as well because CAAD frustrates me*"(S6). The second facet was that there was insufficient time for a student to learn a new package when it is needed for a project alongside the studio project time line, typical quotes were:

> *"Learning a bit on your own is one thing, but learning a whole package is ... without any assistant or instruction is another thing,"*(S6).

> *"To be fair, to pass all courses you need to be quite self-taught a lot of it".* (S1).

The third mentioned facet was when a senior student needed to use CAAD for a certain task but could not because of a lack in her skill set, which influenced her self-esteem and a feeling of been "behind", typical extracts were:

> *"Because I used to find it really frustrating ... I didn't know what to do. And I fell so behind*".(S4).

> *"It's the stress as well, you think you're behind but you have to do it but you're so behind and you need to learn it. Feel like, you know, if I just learn it maybe it would be quick when you get to the end*."(S6).

> *"And it's a shame because there are some people this year that have said, oh well, I don't want to do that because I can't ... I don't know how to do it in SketchUp, and I don't have time now to use SketchUp. I hope that won't put as in disadvantage being with a practice and they say: you can do this and this."* (S1).

Asking other students was not appreciated in such a situation especially when the students are senior; they are reluctant to ask the younger students to solve some of the problems. This suggests that there is a deficiency in recourses for senior students especially when these were needed in a short time or while working on the design and focused.

> *"And, you know, everyone's different, so you can't go up and say to somebody, "Can you spend three weeks teaching me to do this," it's not practical and there's no other way to learn it"* (S6).

> *"I was asking some of the boys at the honours year to help me with some CAAD issues I was having on the computer, "Excuse me, do you have any time to fix that problem?"* (S1).

> *"Well last year we didn't get taught to use CAAD but we're expected just to know how to do it"* (S6).

In general, the lack of CAAD skills and gaps in students' knowledge requires continual development in order to elevate their level of CAAD practice and experience to the level of expectation. S6 stated:

> *"Well last year we didn't get taught to use CAAD but we're expected just to know how to do it"* (S6).

In brief, there is a contradiction between the actual level of CAAD skills of senior students and the teachers' expectations of performance, which should be elevated through ongoing development.

8.2.10 Project model appraisal

Not surprisingly, students responded negatively to any project model which helped them to learn new CAAD-related topics or programs. Students' post project experiences did not highlight any recently learned issue apart from a "*few*" or a "*couple*" of shortcuts (practical). However, one student stated that she had used CAAD differently because of this year's (2006-2007) project (which was also observed in the students' reflection on their analytical project strategies, shown by interviews in sections 7.2 and 7.3).

> *"Maybe a few shortcuts and that on Photoshop and stuff, but I would say I've learned, I haven't learned any new programs this year because I know kind of pretty much most of that stuff. I think you always learn, like, a couple of shortcuts then how to do that and (how to) use an alternative."* (S5).

> *"It's basically the same, it's just learning to use shortcuts and things, so I've learnt that, kind of I would say using it differently."* (S6).

There was no deliberate integration between CAAD and this year's (2006-2007) project, or clear direction in using CAAD as part of the project model, especially the proposed projects which were described as complex and relatively big compared to previous years of education.

On the other hand, another feature of this year's (2006-2007) project model was the extensive use of precedents; precedents were given as part of project problem identification studies, and students were asked to provide a precedent for every conceptual proposition. Consequently, the discussion focused on the purposes of precedents in general, and the precedents that were required for this year's project model in particular. The students had been using many precedents within the project model. The precedents used in their work were presented as references to the conceptual work (part of the final presentation).

In choosing a precedent, students' criteria varied according to the investigated design issue or the differences in level of detail. Such as "*the materials that they have used or certain type of site, how the building is located on the site there, certain parts are angled for a reason, or looked to the south*". (S2). Another student stated, *"Other ones perhaps environmental issues, the building might be look ugly but it could be good ecological example. So you could incorporate that." (S6)*. A variety of precedents present various design issues "*because what you are looking for in a precedent (those specific criteria) you will never find in one example."* (S3).

Architectural precedents varied from images of what buildings look liked or a collection of similar featured buildings, to the ones being designed which were precedents from the subconscious. S6 stated:

> *"Because ideally, on daily bases, you experience architecture like your house and your school and stuff, a lot of the stuff that you have seen somewhere is not that you have but it is in your head somewhere*."(S6).
>
> *"Subconscious as well, I mean I find a lot of trouble to find a precedent for what I want to do I just come up with what I want to do and then I have to go and spend days trying find precedents, because some of the tutors believe that what I should do. And I am like, but I have already decided what I wanted to do so why I should go and find someone who did something similar*"(S6.)
>
> *"Or even you have seen it and you know what the building is but there is nothing about it there. Few times, I have seen buildings down in London, or Glasgow and Edinburgh that I noticed there is not spectacular kind of photographs, I went and took two photographs, but still there and you want to reference it and talk about it."* (S5).

Participants mostly considered precedents on the surface level of design, form and materials. Precedents were mostly studied and collected on the surface level of schemata, leading us to ask: what is the role of design methods and design processes?

> *"Yah to give you a reason, well this is the materials form of what I am wanting, this the experience of light that I am wanting here ."* (S3).

"I think in different ways I tend to if I find something I keep it, whereas some people really go and too often look for more really similar to something else whereas I tend not to do that."(S5).
"It depends on what you are doing. Sometimes you will find what house or looks like what I imagine. Oh, I will hide that one for me."(S3)

However, as part of studying architecture through precedents, the discussion revealed that students were also interested in learning design methods and projects of leading architects or artists. Typical extracts were:

"Yah, to know and learn what other people do and affect what you do." (S1).

"Like 57 10[3], when they say we did this and we did this. That is great though." (S6).

The students were interested in learning about leading architects' design methods through their projects, but would not take the time to look for this information. One student states, "*It is very hard to go and read, there is couple of architects that have written books about their methods*." (S3). Another student stated how useful it could be to read about other architects' design methods and processes and confirmed the aforementioned point:

"*the rationale behind what they have designed if you are reading AJ (The Architects' journal) we did this because and did that because I suppose we can do research in that way but not consciously go to the library and look for their books to know about methods*." (S6).

Another student identified that studying others' design methods through examining their presentations could be useful for enhancing the individual design process. However, the same point was raised regarding information availability. This suggests that students had no determination to find information which would enhance their design processes and methods, as stated by S5:

"I looked at Malcolm Fraser's project I had a couple of presentation there how you did it and why you did it, that way I examined at that point I took those rules and put them into projects for a little while but because that time I had the information in front of me." (S5).

Another participant agreed to its importance by stating "*I do pay attention to architects presentation and drawings"* (S6) but disagreed with embedding these methods in my own: *"I do not think I would incline to do it*" (S6), that is using similar methods for her design process.

[3] It is a lecture series that Scott Sutherland School is taking part in. it is run by the University's Architecture Society, the society aims to create a link between architectural education and architectural practice. (More information can be found in http://www.5710.org.uk/aboutus/about.php#).

To enrich the discussion with another perspective on teaching CAAD, the moderator presented a relatively new approach to CAAD teaching which was based on the ontology of professional architects, such as *Peter Eisenman, UN Studio, Greg Lynn, and Frank Gehry.* The aim was to discus their methods and examples in teaching CAD design and was entitled: "Urban and Architectural Design with CAD". This course was led by Dr Henry Achten[4] (Achten and Reymen 2005; Achten 2003) at the University of Eindhoven. A description of the course and examples of students' work were presented, with emphasis on the relationship between design theory, CAD theory and architectural theory (Achten). Most of the participants responded positively and were curious to learn more about the method. They were mostly impressed with the theoretical–practical relationship between design and CAAD demonstrated by leading architects' design methods and their projects, and agreed that the way they use CAAD is influenced by the way they learned it. One student (S6) stated:

> *"I think it's interesting. I am kind of jealous actually that they've obviously had so much more information, because I spent quite a lot of my second year struggling to learn CAAD because, you know, six or seven people in the class can do it perfectly, and I'm, like, I just, I've never been taught, I just don't know how to do it".* (S6).

The example directed the discussion towards other students (exchange students) to reflect on what other institutions' are teaching, with respect to 3D skills, techniques and programs. S2 stated:

> *"If you looked at some of the exchange students' work they have taught different packages and different ways some of the 3D work looks like a photograph, it does not look like a CAAD drawing. And I think if we had been taught other techniques of CAAD and other programs may be, probably would be better*". (S2).

Participants were aware that different teaching methods may produce better results, as knowing about the appropriateness of a tool would enable students' to go beyond project presentations to the presented structures of these projects, which may affect their practices in using CAAD early for concept design or design exploration. P6 stated:

> *"It would be really great to be able to see these structures in those drawings. It will be great to know how to do that and if you did know that would you be far more inclined to use CAAD earlier on in the design rather than ... I think you stay away from it until you need to. Just have a clue how to do it; I do not know what all these things mean."* (S6).

[4] http://www.ds.arch.tue.nl/7m690/

> *"Sometimes these things make you run away with the design and people produce ugly big blobs because CAAD packages can do that and the design are just because it can".*(S1).

> *"Quite often, the ones who are producing these buildings they need suddenly to step back and look at its context ...can do it yah. I would not choose to do that anyway*."(S3).

Another student commented that even if she had acquired such knowledge, she would not use it because of the way she had been taught to design, that is the habitual practices of architectural design and education. Other participants placed the use of new methods (CAAD based methods, digital design methods) in the conventional context of studio teaching. Typical quotes were:

> *"I don't know, I think doing architecture and doing it the way we've been taught to do it, it's just it's ... I think the way that my mind set as well, it's too difficult to try visualise things on a screen."* (S6).

> *"I don't feel like it a good practice if we didn't do any sketches"* (S5).

> *"Yes, because moving on from that part, developing design skills comes from pulling your eye, pulling your attention to detail, and you get that attention to detail not by drawing but from observing the drawing. And if you didn't do that in the first couple of years, especially at school, you know, architectural school, I don't see how you could go on to develop that design skill."*(S3).

These responses were based mainly on students' mind-set and the habitual practices of architectural design and education. They explain how design learning and knowledge has accumulated over time and practice students could not contextualise CAAD or describe CAAD as "*acceptable*", or "*enjoyable*". Typical extracts were:

> *"With context and stuff may be it is a freer and cultural as well. What is enjoyable, and what is acceptable...."* (S3).

> *"Yah because Britain got quite; especially in Aberdeen the architectural culture is conservative as conservative gets."* (S6).

The above extracts illustrate that students' methods of learning can be influenced by their cultural perspective suggesting that it not just habitual practice that affects learning but also the image that architecture is conservative and resistant to change.

8.3 Summary

In summation, a focus group was held immediately after the end of year hand in, to improve our understanding of the role of CAAD educational methods in the way it was used during the two semesters and the impact of CAAD on visual thinking. Focus group findings provided an extensive image of students' preconceptions of CAAD in relation to past, present and future experiences.

This was also the case in the earlier phases of the studio reflection, some of the interviewees (students) showed a tendency to separate what this thesis and most design studies termed as CAD (generic, interdisciplinary) and CAAD (more specific to architectural design, disciplinary). To provide a contextualised meaning of the term CAAD the students were asked what CAAD meant in their own language and terms (knowledge and experience). Students were keen to separate the term CAAD into AutoCAD and SketchUp, as they were aware of the characteristic differences between the main two software programs (survey results) that they had used during the project. They were aware that both had different capabilities, presentation criteria and working methods.

With respect to the term CAAD, the discussion suggested three things: 1) students' definition and meaning was based on a practical context that is the way it was used by students during their university education, 2) CAAD was introduced to students in a detached manner from its theoretical evolvement, and 3) the differences between CAAD software programs such as AutoCAD and SketchUp, which are totally different in the way they work.

The practical use of CAAD suggests that if AutoCAD was used as the only CAAD program then the cyclic process would consist of two stages of media exploration, conceptual sketching and CAAD, but this may change when more than one program (SketchUp and AutoCAD) are applied, then the cyclic process would include three stages of exploration: conceptual sketching, SketchUp (3D exploration) and AutoCAD (mostly 2D). Apparently, this would imply other differences in the mode of exploration whether 2D or 3D.

The discussion revealed that working with CAAD does not change the students' sketching habits and tendencies, as jotting down how to draw or what to draw is still an essential task even if they are mainly working with CAAD. Moreover, drawing in CAAD is a multiplex process compared to sketching. Another way to interpret the same observation pertains to working memory load. Therefore, hand drawing will continue to provide a template for CAAD procedural steps but at the same time the act of drawing should be acknowledged for providing a better understanding of what has been drawn.

The focus group also explored tutors' role and many influences became apparent. The tutors' approach and attitude towards CAAD are important. Students agreed that tutor's attitude towards CAAD use (AutoCAD in particular), influenced students' attitudes, hence what CAAD was "allowed" to be used for in the studio. This point contradicts another identified role for studio tutors, that is in appraising CAAD representations, with many students referring to the contradiction between the quality of students' CAAD representation and the conceptual content. This brought confusion and subjectivity of architectural representations, which seems to be commonplace in architectural design. Tutors' should be more aware of that aspect of student's work and try to reach beyond the surface and convince students of the conceptual quality away from the quality of presentation, to help the student acquire the critical ability of judging the produced representations.

With regard to the project model and studio process, CAAD would affect the design process timeline as it was cited by the student. Students' description was focused on CAAD practicality in reducing the time required to do the changes, without any other conceptual implications. However, this feature had implicitly influenced the number of changes that a student may undertake, to increase the continuity of the design processes. Moreover, these changes cannot be claimed to make the design process more successful or suggest conceptual iterations rather mere changes in dimensions or heights. However, the students could not make a connection between CAAD and any design aspect that CAAD was helpful in solving in relation to a design problem within the context of the two semesters' projects, that is there was no CAAD contextualised implications on design problem solving. Instead, they locally related CAAD to other projects within the class and globally to digital architecture or what they perceive as such.

When they were asked whether CAAD is important in aiding design, they were hesitant to describe CAAD as aiding (we think that this might be related to architect's ego and authorship) but after some time there was a gradual shift in their views, when they had the sense of what is useful for them by summarising some of their design-CAAD praxis. However, they acknowledged the CAAD contribution to make specific buildings feasible on a global level.

Most of the participants indicated that the teaching of CAAD did not receive sufficient importance through their years in academia. They referred to themselves as a "*transitional generation".* As the changes they witnessed were various on the level of CAAD teaching and assignments. It is interesting to think of the relationship between when CAAD was taught and took place within the architectural curriculum and when students felt that they need to use CAAD, when the project became complex and difficult to manage but then they had no access for the right skills. Students' needs were overlooked, thus learning CAAD became self-directed learning.

While reflecting and discussing their CAAD experience over four years, the focus group discussion indentified the following issues:

- as opposed to studying architectural design, some of the students were acquainted with CAAD through pre-university teaching. Thus CAAD engagement through university teaching was not their first experience.
- comparing both contexts suggests that the motives to study CAAD were different.
- CAAD learning at later stages of architectural education became self-directed learning.

In the present study (case study), the students stated that they had the CAAD course on the 2nd year of their education. The relationship correlates negatively with the time that their projects become more complex. This shows that students of architecture are taught CAAD at an early stage of their education where they have strong feelings of not needing to use it as they have to design relatively small single storey buildings. There was no need to use the learned skill or they could not contextualise the learned skill within their project framework at that stage. Based on the discussion, the prevalent feeling was they did not feel that using CAAD was important or needed when the project was easy (*one single storey structure*), but that changed as the given project was described as complicated (based on its number of stories and how big it is –larger) when they felt that CAAD was indispensable as they described that the project as complicated (multi storey building /larger). Students' needs were overlooked thus learning CAAD became self-directed.

On the other hand, participants had concerns regarding rapid technological developments, skills attained through education and workplace and which skill set is needed more for their future career. These concerns varied from continually changing software to workplace dependency of technology and CAAD. Much of the learned skills (CAAD) takes place at the learner's (graduate's) initiative. This suggests a gap in the way CAAD is taught, not only at this critical stage of students' preparation but to qualify them for the workplace and should involve a systematic process of learning that is based on project size and skill levels of CAAD and whether their skills are in 2D or 3D, and also to initiate a move from 2D to 3D. Apart from the right skill set, students identified the importance of gaining tacit knowledge of design structures and forms alongside the operative skills of CAAD software programs, which promote CAAD flexibility in conceptual design.

The following study addresses some of the issues raised on the level of macro interaction between CAAD software programs (tools) and students, to exemplify the emergent issues that may also occur or applied on the micro level of self-communication.

9 Study Four: Design Protocols

This chapter outlines the procedural steps for data analysis. The protocol study method is at the heart of this thesis data collection and as discussed in section 5.5 is the main data source for investigating CAAD's "conservative" utility in the conceptual phase of students' design process. This study data collection is presented in Figure 9-1.

The first section introduces the experimental method outlining the experiment design, task and procedure. The second section describes the steps of data preparation and the analytical methods that were employed. The third, fourth and fifth sections present protocol study analysis and results, and the sixth section presents the linkograph analysis and results, and finally participants' comments are presented.

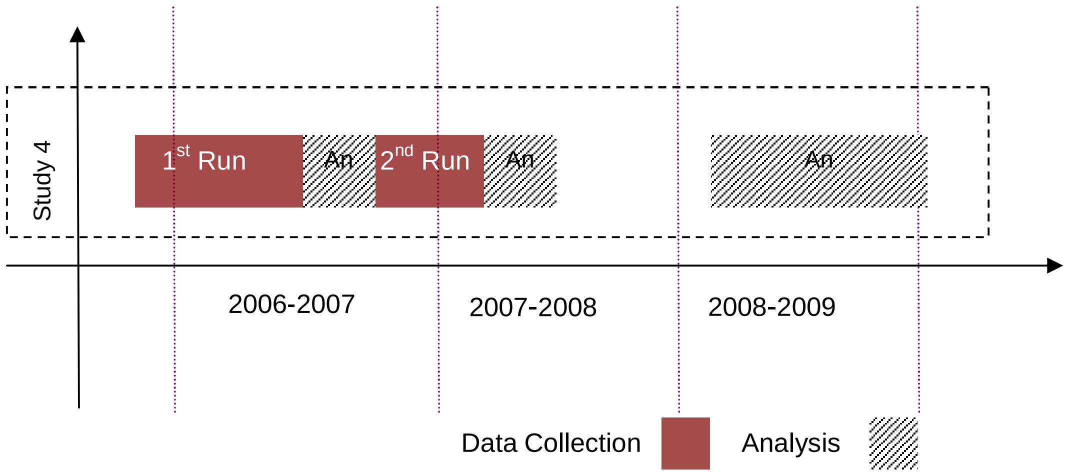


Figure 9-1 The protocol study data collection and analysis timeline.

9.1 Method

This study utilises a highly structured think-aloud method to investigate the design process of final-year students at Scott Sutherland School of Architecture and Built Environment. The main objective for this study is to examine how CAAD software programs support the individual design activities and to explore how a design student would interact with external representations while designing (visual thinking) with CAAD. Furthermore, the study results reflect CAAD's utility by a cross section of architectural design students and final year architectural technology students. Both have been educated to use CAAD at the final stage of the design process.

9.1.1 Experimental design

To generate CAAD-based design protocols, the following experiment was set and repeated in two runs (2006 and 2007) of data collection. The approach follows that defined by Van Someren, Barnard and Sandberg (1994), a similar approach used by others (Bilda 2001; Bilda 2006; Tang 2001) and practically tested in an exploratory phase of data collection. This was useful in revising the initial plan regarding the experiment duration and phases, and incorporating CAAD based representation.

An architectural design brief is presented to participants who then select their preferred CAAD program (AutoCAD, SketchUp or ArchiCAD: these are the programs which are available at Scott Sutherland School) to attempt the design task. Participants were asked to verbalise their thoughts during the task while being video and audio taped.

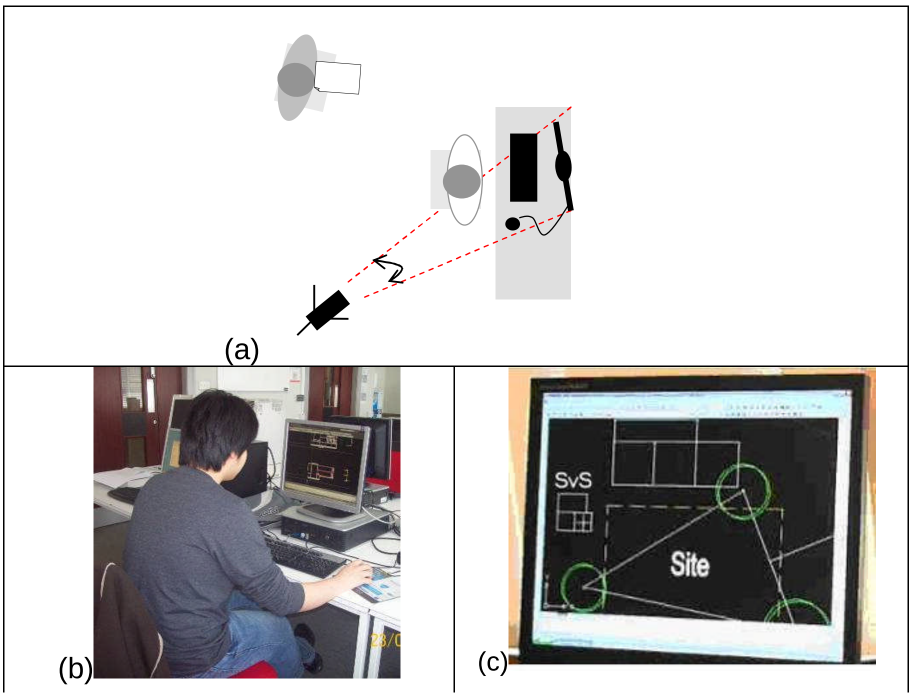


Figure 9-2 (a) Experimental setting (b) Participant's position (c) Camera snapshot (the recorded field).

The experimental setting is shown in Figure 9.2.a. The digital camera is arranged to look over the right shoulder of the participants towards his/her computer screen, to minimise the impact on the participant being recorded (Van Someren, Barnard and Sandberg 1994; Bilda 2006). The researcher sits to one side, observing the process and making notes of the design session.

An AutoCAD drawing (shown in Appendix D-2, p.372) of the site was provided in 2D with a cross-section. The design task was to design a gathering space; the required outcome being a 2D concept and preferably 3D conceptual model while detailed plans, sections, and elevations were optional. The experiment procedure is explained in the following section.

9.1.2 Procedure

Each participant went through the following sequence of steps:

1. The researcher read the experiment instructions to the participant, explaining the design session plan: site inspection (if needed), thinking aloud while designing and debriefing. The participant was required to design a gathering space within the given site while using one or more CAAD programs within the design session lasting approximately 60 minutes.
2. The design brief was given and then an AutoCAD drawing of the site was provided to familiarise him/her with the site. The participant was then asked whether a site visit was required (the proposed site is adjacent to Scott Sutherland School sharing one campus).
3. The thinking aloud method was explained. The participant viewed a (5) minute clip, which was taken from one of the recordings of the pilot study as a demonstration of what they were required to do during the experiment, in terms of the thinking aloud process. The clip presented the experiment setting, the recorded scene and the verbalisation content. Afterwards, the participant was asked if s/he felt ready to start.
4. At this stage, the video recording commenced and the participant was asked to design using CAAD program and talk aloud.

All participants stopped when they felt that they were satisfied with their design result. When the participant felt ready to present the finished idea, s/he was asked to provide a brief conceptual explanation of the final design. This was followed by a debriefing phase, which included some of the observations from that specific experiment session, participant's reflection on the experiment situation, and the conceptual design involved. The final phase lasted for about 30 minutes.

9.2 Data Preparation for Analysis

In the context of think-aloud (concurrent) protocols, segmentation and coding are the procedural steps of analysis (Van Someren, Barnard, Sandberg 1994). The data from each experiment was prepared to be analysed using Transana software[5] (version 2.22) for coding video/audio data, Figure 9-3. This added another step in the management of protocol data. Having explored other qualitative data software such as Nvivo, it was decided that Transana was most suitable for the analysis required. The Transana platform provides the ability to quantify the time spent on each code and the number of codes in every protocol. It calculates time for each coded activity in relation to the total time that the participant spent in designing.

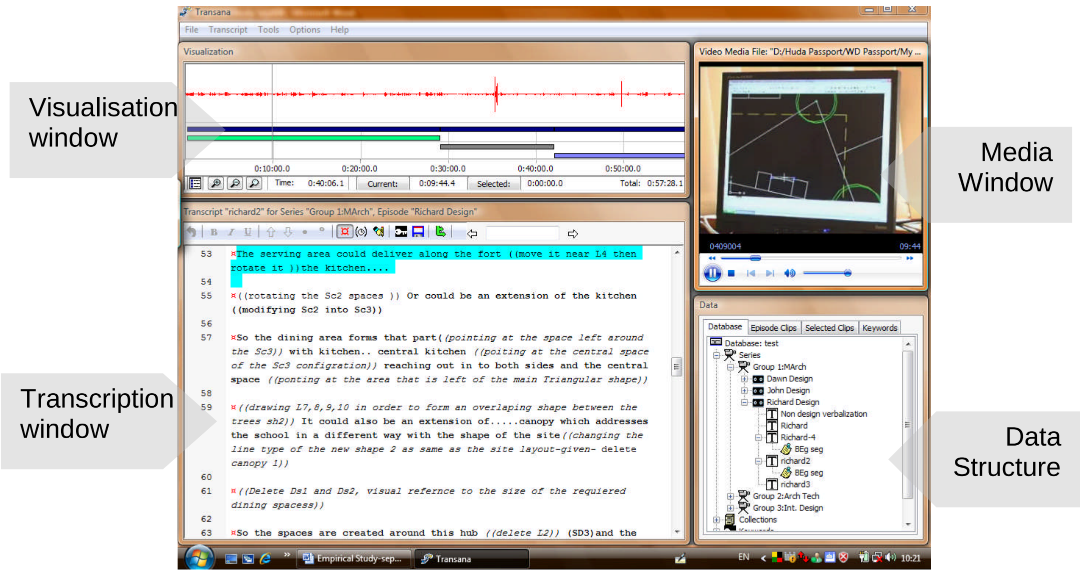


Figure 9-3 Transana software platform (text, time codes, visualisation window and the protocol study database).

The pre-analysis data preparation involved six steps: (1) cutting the video recordings into three clips, (2) transcribing the parallel modes of thinking, (3) assigning clips by time stamping, (4) segmenting arbitration, (5) data coding by

[5] Transana: http://www.transana.org/index.htm

assigning keywords, and (6) coding arbitration. These steps are explained in the following subsections.

9.2.1 Step one

The aim of this step was to define the exact duration that the student had spent in conception. Practically, this includes cutting the design session video recording into three different clips by extracting any time spent not related to the study that would eventually affect the actual time that the participant spent in designing. As a result of this process, the resultant clips were named as:

- *Pausing clip* - includes any pre-designing activity where the participant has spent time trying to settle and make himself familiar with the experiment situation after seeing the five minute clip as part of the think-aloud training.

- *Designing clip* - includes the designing activity, in referring to conceptual design and CAAD drawing changes that each student has made to the initial AutoCAD drawing of the site, which defines the sequential shifts of ideas over time. This relational analysis can also include the preparation for the next state of the design (the latter drawing develops from the former drawing), which formed the largest.
- *Debriefing clip* - includes post-experiment questions to clarify some aspects of the designing activity that had been observed by the researcher.

This step was important in terms of utilising Transana (version 2.22) software, (Figure 9-3), as an analysis aid for time calculations, as it calculates time for each coded activity in relation to the total time that the participant spent in designing.

9.2.2 Step two

The aim of this step was transcribing the raw protocols (designing clip). In this process, the verbalisation data provided by the participants was transcribed into text. First time transcribing was concerned with the exact wording of the think aloud (verbal) protocol (interprets its contents ‘mostly’ verbatim), and was completed by inserting time codes (table 9.1 and Figure 9.3). Afterwards, with respect to verbal/visual data complementarity, discussed in section 4.1.1, the parallel actions of the other critical aspects of thinking (external representational actions) were described and inserted parallel to the verbal protocol and its time stamp. This was achieved by explaining exactly what was happening at that point in time regardless of whether the participant was talking or not. This included pointing actions such as pointing at the screen using either the hand or the mouse (or cursor) and drawing actions, as shown in example Table 9-1. Finally, the debriefing clips were transcribed.

Table 9-1 Two different examples of the parallel protocols transcription

Seg. No. (Clip ID)	Transcription
Seg. 17	(0:07:04.7)((pointing at the opposite corner and also pointing at the one that he has moved))*Could be corner may be the kitchen addresses* ((rotating the Sc and move it towards the east southern corner)) *the dining space and seating area is separated from them to the South East* ((rotation Sc 1 and modifying Sc1 into Sc2 linear shape))
Seg. 18	(0:10:24.9)*So the dining area forms that part* ((pointing at the space left around the Sc3)) *with kitchen…… central kitchen* ((pointing at the central space of the Sc3 configuration)) *reaching out in to both sides and the central space* ((pointing at the area that is left of the main Triangular shape))

the italic text denotes the verbal protocol and the standard text denotes the non-verbal activities (SA1 extract)

9.2.3 Step three

At this stage, based on the theoretical framework of the study (in section 5.6) the raw data was transformed by inserting time stamps to form segments (clips) within the Transana analytical platform. Transana software embeds video time codes into the transcript and makes the synergy between visual-verbal modes of data easy and ready for arbitration. This is explained in section 9.3.2.

9.2.4 Step four

Arbitration of segments was carried out for every protocol by recoding the same protocol after a period of two weeks. The agreement percentage of the coding between the first encoding run (version one) and the second encoding run (version two) was then computed to reach an arbitrated version (third) by comparing the observed discrepancies and choosing the most reliable one. (For a full review of the interreliability coding method this thesis has employed, the reader is directed to Purcell et al. 1996).

9.2.5 Step five

In this step, the data was made ready for encoding by assigning keywords (codes) to each clip (segment). Gero and McNeill's (1998, 1996) design process coding scheme was adapted and used to encode the transformed data. The design protocol encoding was based on three schemes: design-process coding, level of abstraction (Gero and McNeill 1998, 1996), and an external representation coding scheme. In addition, the protocol's CAAD drawing was categorised into specific types according to their purposes and mode of visual engagement (2D, 3D). This hypothetical coding was carried out in parallel to structuring the productivity of the design process with respect to design moves and links (Goldschmidt 1995).

9.2.6 Step six

This was the last step in which the coded protocols were tabulated for further analysis and investigation. Excel was used for tabulating Transana's time calculation for every coded segment from the automated episode report and for all codes or keywords. (An example of the episode report is provided in Appendix G-2, p.384). Finally, these six steps (step one is not shown) are outlined as a process in Figure 9-4, where this research process is compared with Gero and McNeill's (1998) and Goldschmidt's (1995) coding methodologies.

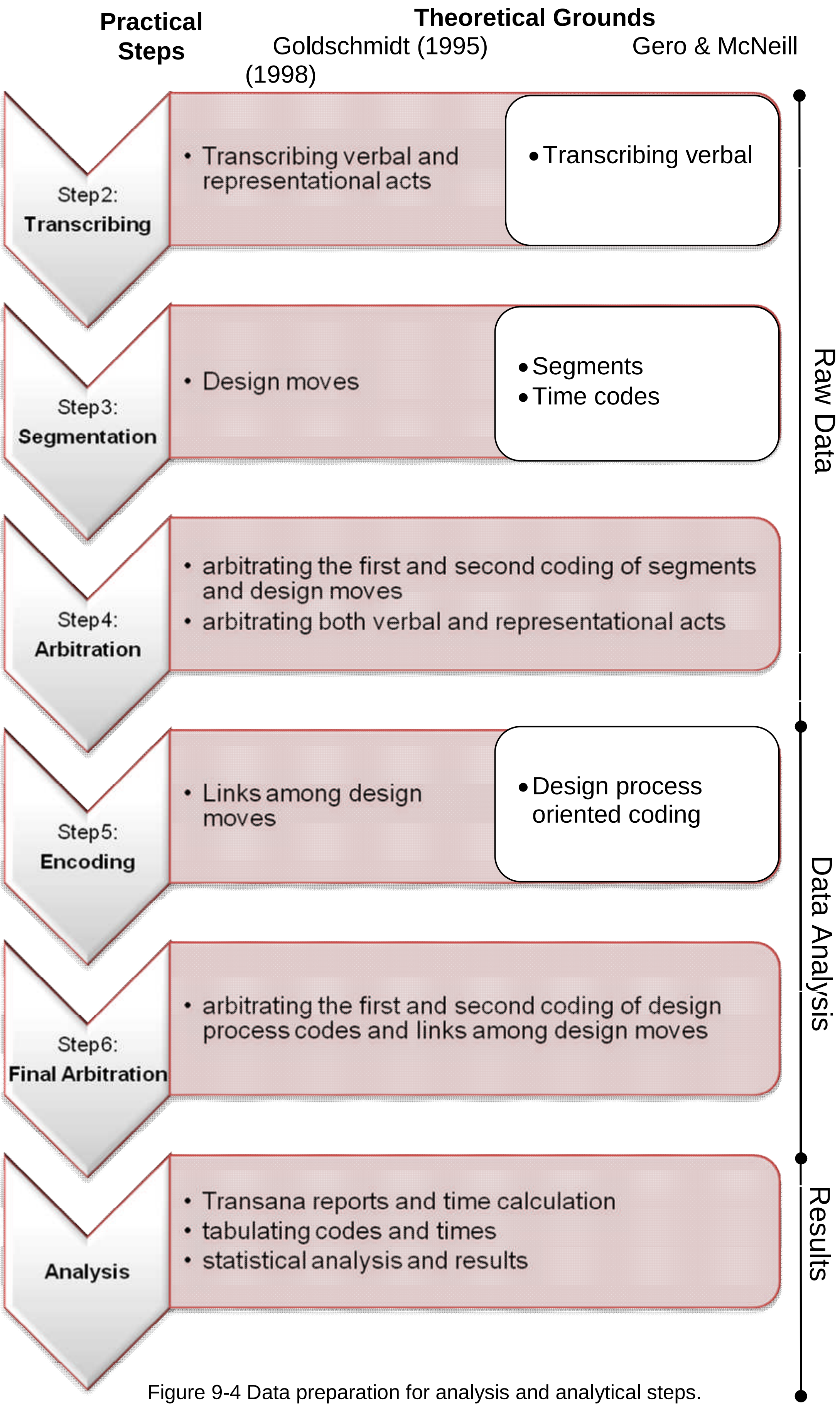


Figure 9-4 Data preparation for analysis and analytical steps.

9.3 Protocol Study Results

In this section, the protocol analysis (applying Gero and McNeil's analytical methods) results are presented in three main sections: the results of segmentation in the first section; coding of the design process representations which includes CAAD drawings, modes of engagement, and the relative time spent in the second section; and the process oriented coding in the third section which includes a descriptive analysis of the design phases, coding percentages, levels of abstraction and external representation acts.

In other words, the following sections (9.3, 9.4 and 9.5) will answer the following questions in the light of the analytical methods that were applied:

- How are CAAD representations used in the conceptual design, and for what purpose(s)? Is the student creating a drawing for presentation or conception, and why?
- In terms of design strategies, does CAAD force the student to behave in a specific way while designing?
- How will the design process correlate with CAAD's external representations?

This section describes the thesis' design protocols, segmentation and encoding constancy. The cases represent a cross section of the same population to reflect on the same educational context of the two earlier studies but through reflection in action under CAAD experimental conditions.

9.3.1 The study protocols/cases

This section reports the preliminary findings of the protocol studies and describes how the theoretical framework (in chapter five) has been applied to the data sets that were selected. The data sets are four design protocols based on the experiences of advanced year students at Scott Sutherland School of Architecture and Built Environment. The students were encouraged (the selection criteria in section 5.6) to participate in the study by their tutors, describing the study sample as confident and motivated CAAD users who had a "good" level of CAAD expertise. Based on these study objectives, in section 5.2, and the criteria previously discussed in section 5.1.4 and section 5.6, four design protocols were selected for analyses. The following paragraph describes the selected protocols as participants.

At the time of data collection, the first two students were studying for a Master of Architecture (MArch) and were labelled in the study as SA1 (1st run 2006) and SA2 (2nd run 2007). The other selected two cases were final year Architectural Technology students, and were labelled in the study as ST3 (1st run 2006) and ST4 (2nd run 2007). Table 9-2 shows the selected cases for analysis. 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.

Table 9-2 General description of the participants.

Participants	Auth/Gend	Age	Stage	Design Clip Duration (hr:min:sec)	CAAD Program (s)
SA1	English /M	23	5 th	00:57:28	AutoCAD
SA2	English /M	22	5 th	00:45:18	AutoCAD/SketchUp
ST3	Asian /M	21	4 th	01:19:41	AutoCAD
ST4	Scottish /M	22	4 th	00:56:55	SketchUp

The last column of Table 9-2 provides further description of the participants, that is with the used program(s). Participants were asked to choose any CAAD program(s) (AutoCAD, ArchiCAD or SketchUp) they preferred for carrying out the design task [the free choice would put them at ease within the design situation]. The selected protocols varied in that respect, and as a result, two CAAD based protocols can be identified. The first type is classified as the use of a single CAAD program throughout the whole session (a *single* CAAD program-based protocol) and the use of more than one CAAD program as a *multi* CAAD programs-based protocol.

In this research, three of the selected cases were *single CAAD program-based protocols*, as the cases SA1 and ST3 used AutoCAD, and ST4 used SketchUp, exclusively. The fourth selected case was a *multi CAAD program-based design* in which the participant SA2 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 9-5 in relation to the program used.

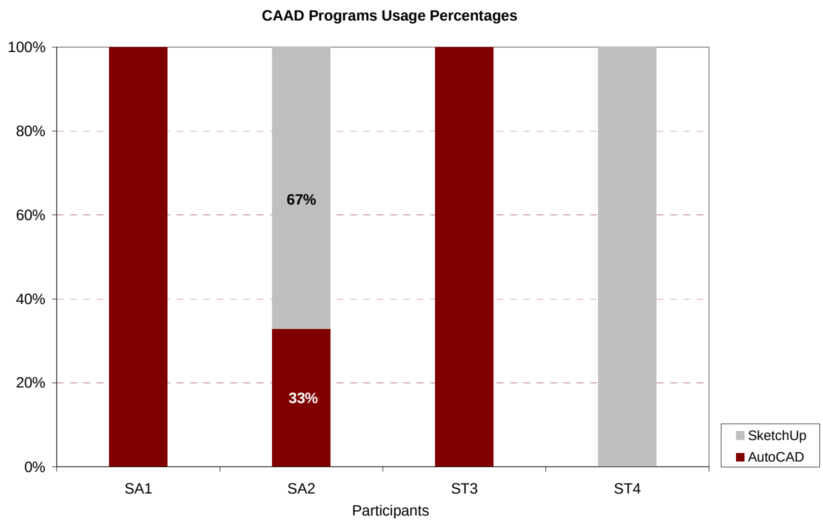


Figure 9-5 CAAD program(s) usage percentages

Most of the collected protocols were classified as *single* CAAD protocol and have chosen AutoCAD. This may suggest two things: (1) most of the targeted samples are skilful in one CAAD program, although they have studied (or have access to) two other CAAD programs alongside the chosen one, and (2) AutoCAD is the most used program within this sample, which confirms that AutoCAD is the most used program within final year students (this triangulates with the survey results in section 6.2.3).

9.3.2 Segmenting and coding consistency

Inter-coding reliability was used to measure protocol segmentation and coding consistency at two different coding intervals. This was performed by computing the percentage of agreement between two codings at two intervals, whether carried out by two different coders or by the same coder (that is two weeks break between the first and the second coding). The agreement percentage is calculated for each protocol by computing the agreement percentage of the coding between the first encoding run (version one) and the second encoding run (version two). An arbitrated version (third) was subsequently reached through comparing the observed discrepancies and selecting the most reliable one (For a full review of the inter reliability coding method this thesis has employed, the reader is directed to Purcell et al. 1996).

Table 9-3 shows the agreement percentages between the three versions; first, second and the arbitrated version, and how the agreement percentages were strengthened after arbitration.

Table 9-3 Segmenting and coding consistency between different coding phases.

Participants	Agreement percentage between	
	1st and 2nd run (%)	3rd and arbitrated coding (%)
SA1	75	90.1
SA2	80	90
ST3	77	89.6
ST4	81	90.3
Average	78.25	89.5

In the first phase, a comparison yielded an average agreement percentage of 78.25, whereas the arbitrated version (third version) compared to the earlier versions yielded a higher average percentage of 88.9%. Other protocol studies (Tang 2001; Bilda 2006; Atman et al. 1999), report agreement percentages ranging from 70% to 94%.

9.3.3 Duration of Segments

The period of time spent in design activity has implications for design behaviour (Tang 2001; Adams, Turns and Atman 2003). Within the context of this study, applying segmentation is based on the shift of focus when new information is added to the design context (section 5.6.1). This means that every segment in the protocol represents one intention of the participating student's design process (conceptual in terms of problem solving and practical in terms of CAAD).

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 (change in intention/ thought transition); 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 cases (69-83), shown in Table 9-4. The average number of segments for the four design sessions is 74.75 segments. The transition rates for each of the four design sessions were 0.85, 0.54, 1.04 and 0.75, successively.

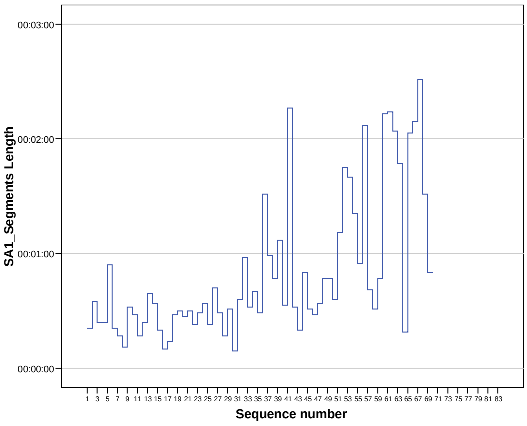
Table 9-4 Descriptive statistics of the four design sessions.

Participants	Designing activity total time (hr:min:sec)	No. of segments (clips)	Mean of segment length (hr:min:sec)	Std. Deviation for mean segment length (hr:min:sec)	Kurtosis for segment length	Std. Error for Kurtosis	Range	Minimum segment duration	Maximum segment duration
SA1	0:57:28	69	0:00:49	**0:00:37**	.590	.570	0:02:22	0:00:09	**0:02:31**
SA2	**0:45:18**	**83**	**0:00:32**	**0:00:23**	6.591	.523	0:02:26	**0:00:04**	0:02:30
ST3	01:19:41	76	**0:01:02**	0:00:36	1.829	.545	**0:03:00**	**0:00:12**	**0:03:12**
ST4	00:53:34	71	0:00:44	0:00:29	-.722	.559	**0:01:46**	0:00:04	0:01:50
AV	**00:59:00** (Total of 238.37min)	**74.75**	**00:00:47**	**0:00:31**	**2.072**	**0.549**	**0:02:23**	**0:00:07**	**0:02:31**

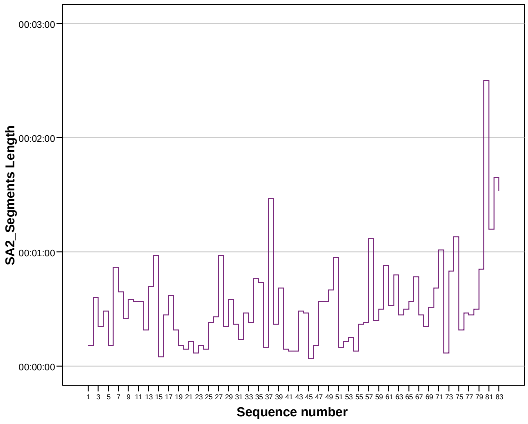
It is interesting that the shortest task duration (45:18 min) had the largest number of segments (83). This suggests speedier shifts of intention and moves compared to the other cases. At this level of analysis, this may be related to the user employing a multi-CAAD protocol.

The mean segment length for all cases 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. Sketching protocol studies report the average duration of segments ranging from 17 seconds to 23 seconds (Bilda 2006 p.47) and from 7.5 seconds to 37 seconds (Tang 2001 p.24). This suggests a longer segment within CAAD protocols, which is relatively high compared to sketching protocol studies.

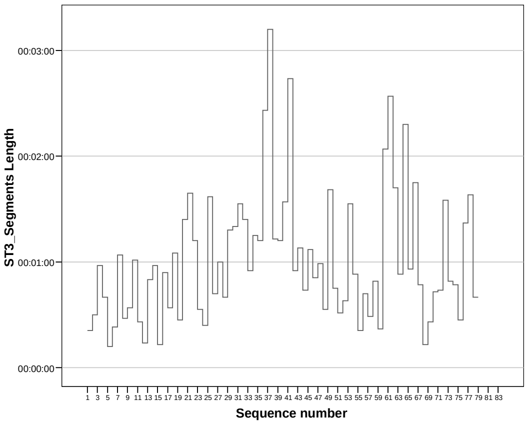
To ascertain how these segments were distributed with respect to the start and end of the design session, plotting the segments duration in sequence (using segment's time series in SPSS sequence charts) provided a detailed visualisation of the length of each segment of the individual protocol and its position along the design process time line, as shown in Figure 9-6 (a, b, c, and d). The segments in general have a progressive nature, that is a later segment's length is longer than the earlier ones. The longer segment is to be found at the final phases of the design session rather than the early phases and becomes more frequent. This was observed in cases SA1 and SA2 with SA1 showing an early progression compared to SA2. This suggests that the segment length in SA1 protocol increases as the design session progresses. The speed of focus shift becomes slower with longer segments. SA2 shows a more balanced interplay between short and long segments along the process, that is fast shifts of intention compared to longer shifts but the longer segments also occur later nearer the end.



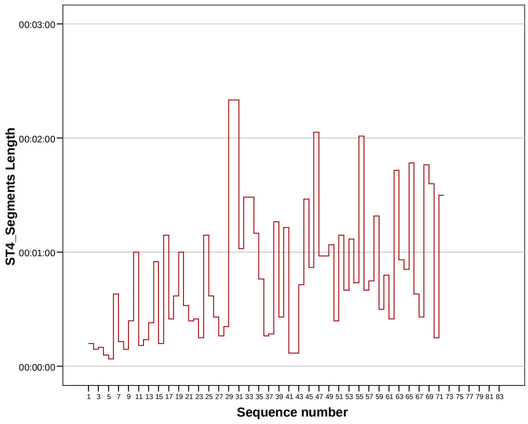
a- SA1 Segments sequence graph.



b- SA2 Segments sequence graph.



c- ST3 Segments sequence graph.



d- ST4 Segments sequence graph.

Figure 9-6 (a, b, c and d) Frequency distribution (segments sequence graph) of the four design sessions.

On the other hand, ST3 and ST4 show another pattern of succession, as the interplay between short and long segments occurred at an early stage and continued as the main pattern throughout the later stages of the design process.

The cases varied in the most frequent segment length, for SA1 the most frequent segment length was 47 seconds, for SA2 it ranged from 11 seconds to 34 seconds, for ST3 it ranged from 40 seconds to 1:12 minutes and for ST4 most frequent segment lengths ranged from 24, 25 and 26 seconds to 1:09 minutes (detailed graphs are provided in Appendix G3, p. 407).

Frequency distribution was used to summarise the variation in segment length for the four cases, in figures 9- 7, 8, 9 and 10. As a result, the four cases had the following aspects in common: (1) The most frequent segment lengths were clustered at one end of the scale which implies that the majority of segments lasted less than a minute and (2) longer segments have lower frequencies (shorter bars) and occur towards the end of the design session.

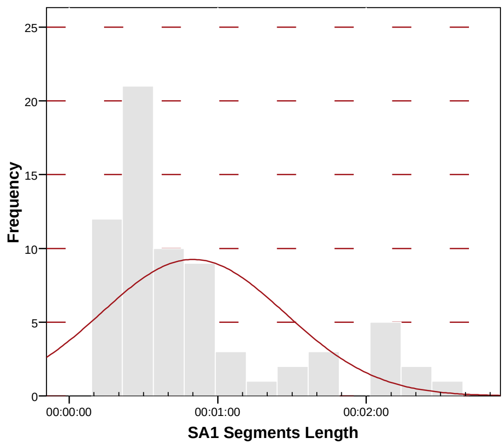


Figure 9-7 SA1 segments length histogram

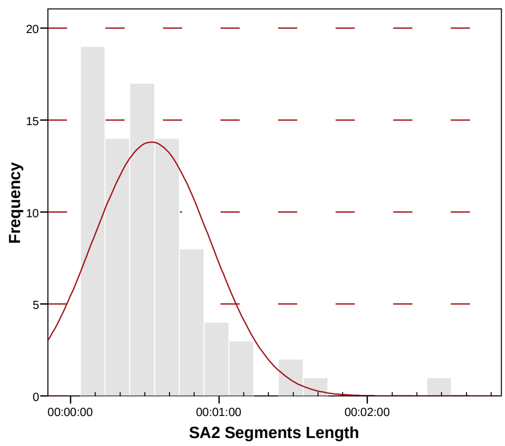


Figure 9-8 SA2 segments length histogram

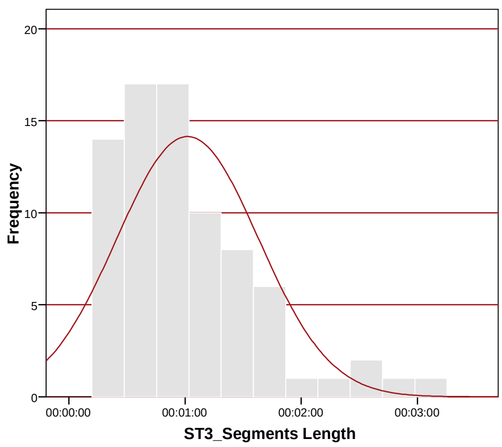


Figure 9-9 ST3 segments length histogram

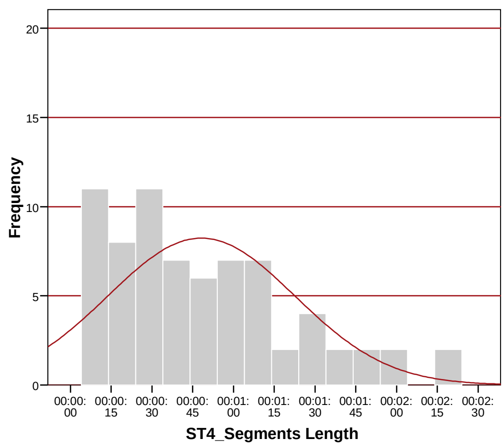


Figure 910 ST4 segments length histogram

Although three of the participating students were able to produce a conceptual proposition in less than an hour, the average segment in relation to the design intention as the basis of segmentation showed that CAAD as a medium affected the design process, as participants needed more time to complete their actions. Thus, a more focused investigation is required to explore the reasons behind the longer periods. These segments were identified (similar to exploring data in terms of data outliers) through the following methods: mapping the segments duration and frequencies (Excel and SPSS) and through Transana's visualisation window, which permitted further qualitative investigation in terms of segment's extensiveness (length and number of the attached keywords or codes).

In summarising a CAAD design protocol, whether it was a single or multiple CAAD, characterisation was achieved through quantification of the protocol segments; the smallest grain of the (conceptual) design process. Thus, segment *status* of the total number, duration and frequency reflected the number of design conceptual intentions. The total number of segments was relatively low with higher durations, suggesting that CAAD protocols have relatively longer shifts compared to sketching protocol studies. Another interesting feature of the conceptual design process was the frequency of shifts. The frequency varied amongst the participants, therefore there was no distinct mode. One protocol which showed a different behaviour in terms of these measures, was a CAAD multi design protocol.

9.3.4 Number of segments

The change in design intention from one segment (design strategy) to another shows how many transitions the participant made during the process. The number of transitions is a measure of the number of times a participant moved from one design/representation activity to another (Adams, Turns and Atman 2006; Atman et al 1999). For instance, one transition could be viewed by moving from problem definition to modelling, or evaluation to generating ideas, or moving from one drawing type/mode to another drawing type/mode.

Thus, the number of transitions was counted in 10 minute intervals to describe the richness of a design phase (cycles) whereby the number of transitions - from one segment to another segment is counted to describe the phase's extensiveness of codes (for any of the coding schemes). The sum of overall segments was estimated for every ten-minutes of the design session. The 3D chart, in Figure 9-11, illustrates the number of transitions in percentage for every interval.

All the cases indicated a similarity in the first and last intervals of the design process phases as they had the highest percentage 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 SA1 and SA2 transitions rate in every interval had a lower rate from the preceding interval. Case ST4, in general, had a similar trend apart from the second interval of the design process whereby the (transitions) rate collapsed below the rate of the succeeding interval (phase). The second was a u-shaped progression, whereby the rate was hierarchical for the first four intervals followed by an increment. The amount of transitions increased in the last two intervals (phases of the design process).

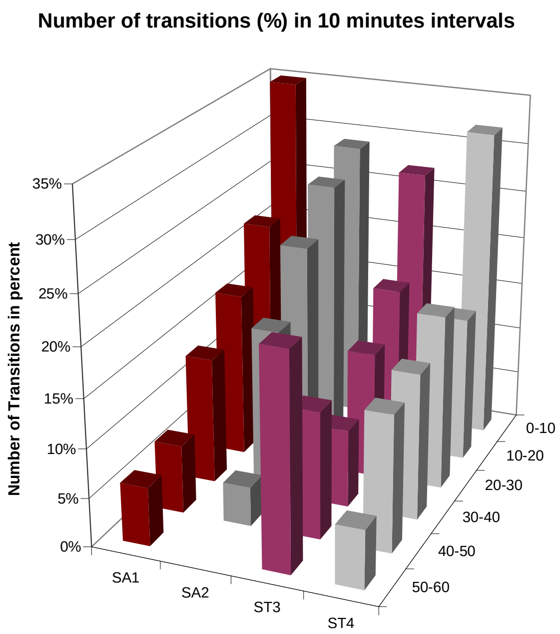


Figure 9-11 The number of transitions (percentage) in every 10 minutes for the four participants.

These results show that the phases of the design protocol varied in the number of segments (transition rate) 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 case. Next, by looking at the content of each interval, a qualitative description was provided to describe what had been done in every 10-minute interval of the design protocol. Table 9-5 provides a brief description for every interval of this study design protocol.

Table 9-5 Brief description of design activity within 10 min intervals.

Intervals	SA1 design protocol
0-10	Analysing the site and its surroundings, suggesting a new layout that is more related to the site constraints (trees and the surrounding buildings) then started to define dining areas and service area.
10-20	Solving the relation between the two defined areas within the layout, then suggesting a canopy that was needed for more area to accommodate the rest of the brief, changing the canopy shape and thinking of the structure.
20-30	Looking at the structure and adding text (having a break) then defining extra areas for the other spatial requirements, and defining the entrance.
30-40	Drawing a section to identify any missing information (the required height).
40-50	Completing the section and then starting the 3D model and applying the required angle for the canopy wings.
50-60	Finishing the roof (wings and canopy) in 3D.
	SA2 design protocol
0-10	Locating seven spaces imitating the spatial arrangement of the campus, by dividing the site into a broad walk and pavilions.
10-20	Locating the rest of the spaces with some modifications and moved to SketchUp to extrude the volumes and work in 3D.
20-30	The roof intersection (new insights) to get them lit from the same proposal
30-40	Deciding on the material (glass) and then started adding textures, e.g. stone for the external wall.
40-50	The path openings and light experimentation.
	ST3 design protocol
0-10	Site layout studies, suggesting the shape, spatial functional relationship through bubble diagram, sizing the actual spaces, and layout.
10-20	Merging both the spaces and the layout to develop two functional schemes for the same layout.
20-30	Take the resulted composition to site to see the relationship of this and the site constraints (tree within the site) then modifying the spatial layout (changed the tree without intending).
30-40	Looking for furniture blocks to see the circulation and the created pattern.
40-50	Adding details and wall thickness.
50-60	Drawing an elevation for the previous moves to set the columns and started the 3D model.
	ST4 design protocol
0-10	Proposing volumetric spaces for the three dining spaces in the site layout to define a courtyard. Suggesting the roof shape as an effect of the surroundings (the slope to the north). And started to locate the kitchen as a connecting form between two of the created volumetric forms.
10-20	Looking at the created form (kitchen) and modified the form by creating a corner. Then he deleted the previously made moves.
20-30	Decided to relate the kitchen to the servery area in two different volumetric shapes and used similar strategy in proposing the toilets area but in a slightly modified version of the previous move (K/S).
30-40	Decide on the courtyard dimensions in 2D then extruded the shape and formed the roof. And decided on issues like transparency by using glass.
40-50	Adding material for the rest and adding details of openings and other materials.
50-60	Adding other openings (from the courtyard –the entrance) and put the model back to context.

As a result, some of the common strategies that were used by the students in solving the design can be identified. The two previous illustrations, Table 9-5 and

Figure 9-11, highlight the association between the lower rates of transitions and the content. The first two cases show, in both illustrations, that the progression is common and gradual from 2D spatial design problem solving to end with a 3D presentation of the design.

On the other hand, the observed differences in protocols ST4 and ST3, Figure 9-11, can be explained as follows: in the second interval of ST4, the student was working on evaluating the created form (visually and functionally), and when the created form was accepted visually, it was rejected functionally as he decided to merge two spaces and their forms. This was compared with ST3 where in the last three intervals, a disconnection in content was observed between the first three intervals and the next three by a detailed level of problem solving for example furniture blocks, wall thicknesses and windows. This, then was increased as he started to inform other requirements (columns and angles) to be able to create a 3D model.

Next, these differences and other facets of the conceptual design process were investigated quantitatively and qualitatively through segment encoding on an individual basis.

9.4 Encoding the Design Process

Transana accurately documents the total time spent in each segment and therefore the content of it in relation to the investigated frame. This feature is well situated for estimating the percentage of durations of each segment over the total time of the design session. Hence, the total time spent on designing can be divided among the sub-designing and non-designing actions (codes). Consequently, these actions can be observed and compared for each session, and between cases.

On the general level of design protocol encoding, each segment of the four design protocols was encoded with respect to CAAD programs and drawing types. They were then specifically encoded with respect to the design process using three main coding schemes (discussed and modified in section 5.2.5); design micro strategies, level of abstraction and external representations.

9.4.1 CAAD representations

The external representations of the design protocols are presented through a descriptive analysis of CAAD drawings and drawings mode. In relation to design drawings, producing a drawing is a dynamic process. It is dynamic in the sense that every aspect of drawing proceeds from "a *general phasing that proceeds from overall, conceptual to detailed drawings*." (Akin and Lin 1996 p.58). On the other hand, design drawings can be classified as creative, and can foster novel concepts, and routine, which is required technically to acquire information and stimulus.

This research applies two ways to document the design protocol external representations: one is to code the drawing type and mode and the other is the coding of the representational actions used. The codes evolved were developed using the Transana keyword system, by directly coding the various types of CAAD drawing, protocol by protocol.

Table 9-6 The codes were used in the descriptive analysis

The codes	Explanation
2D- CD	2 Dimensional conceptual diagram
2D-IS	2 Dimensional informative section
2D-CE	2 Dimensional conceptual elevation
2D/3D M	The interplay between 2D and 3D views
3D-CM	3 Dimensional conceptual modelling
3D-PM	3 Dimensional presentation model
NA	No change, no drawing acts

Through this coding, visualisation of the design process was enabled, drawing patterns in terms of: (1) drawing type, that is segments were coded in relation to the participant's preference to draw a certain type of CAAD drawing, (2) working mode whether 2D or 3D; this involves drawing, looking and inspecting to reflect on his design-constructed world, and (3) the time spent on each drawing (its duration). However, a drawing type refers not only to what the student is actually drawing but also to other visual thinking activities, such as, visual engagement via looking and reading. Table 9-6 shows the codes that emerged from drawing descriptive analysis.

Coding the four design protocols provided the durations for every drawing and engagement that occurred through the design protocol. By tabulating these durations, the total time of engagement is computed as a percentage of the total duration of each protocol, which was completed using Excel.

9.4.2 Descriptive analysis of CAAD drawings

There is a direct relationship between the drawing purpose and the time length that a student spends in drawing or fulfilling the purpose of that particular drawing. The design activity representations are presented in Figures 9-12 to 9-15. These design activity representations are shown as a successive series of coloured rectangle stripes along the timeline of the design process. The strip shows the duration of a drawing activity through its length. Each activity differs from the other activities by its colour; the whole series of stripes gives a quick view of the drawing activity pattern.

All participants created different drawings and spent various amounts of time working on them, whether conceptual, presentational or informative (the drawings are presented in Appendix G1). Looking at the drawing as a process, SA1 provided the study with a single CAAD program based protocol, where he used AutoCAD as the main drawing program. His created drawings included three main types: two-dimensional conceptual diagram (2D-CD), two-dimensional informative section (2D-IS) and three-dimensional presentation model (3D-PM). 2D/3D CM is considered as the transitional drawing type between the two main modes (2D and 3D) of drawing. The relationship among these drawings is sequential, as he considered the functional spatial aspects of the design problem –through 2D diagram- in the first drawing where a satisfied layout for the new design was reached. Then one question triggered the need to draw a section to find the answer to "*what is the difference between the top road and the site?*" that is, consulting external information through drawing. He then started the final drawing of a model which is coded as presentational as there was no conceptual change, he just applied all the generated information.

On the other hand, SA2's multi CAAD program based protocol used AutoCAD for the early phases and SketchUp for the later phases. The drawings created included three types: two-dimensional diagrams (2D-CD), three-dimensional conceptual model (3D-CM) and three-dimensional presentation model (3D-PM).

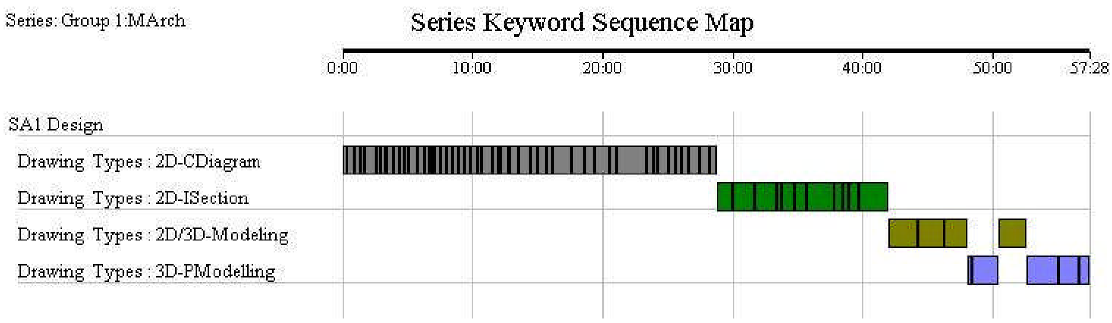


Figure 9-12 Drawing Process of SA1

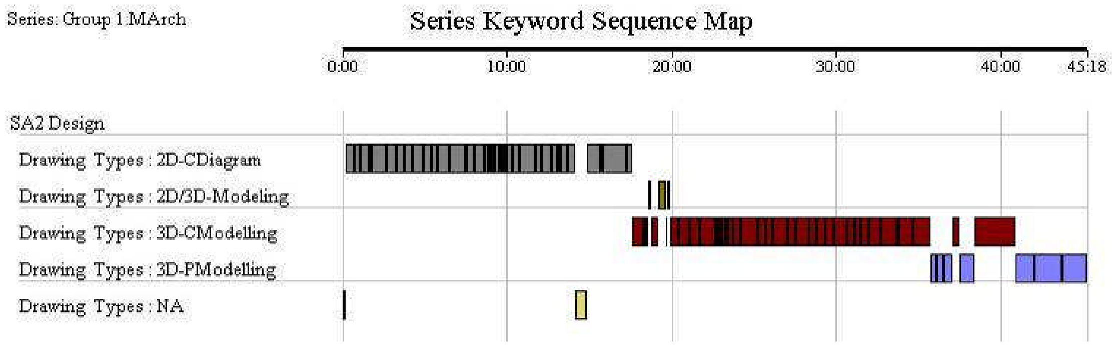


Figure 9-13 Drawing Process of SA2

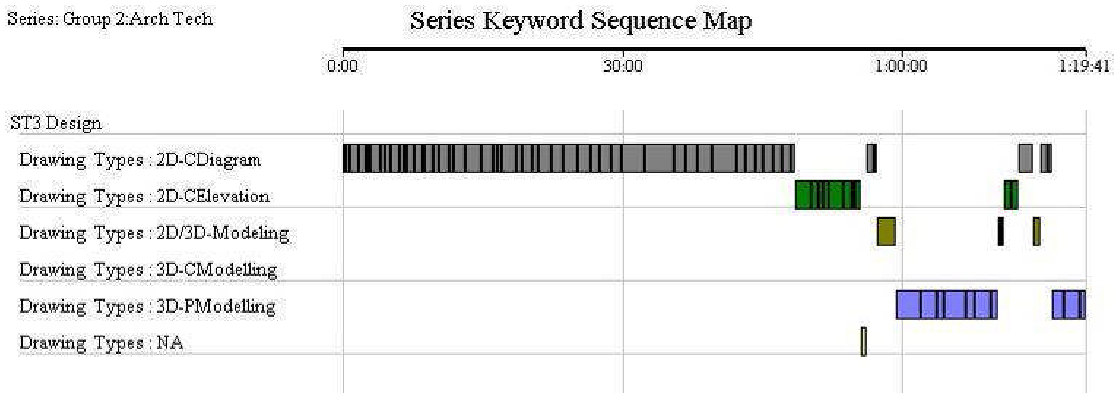


Figure 9-14 Drawing Process of ST3

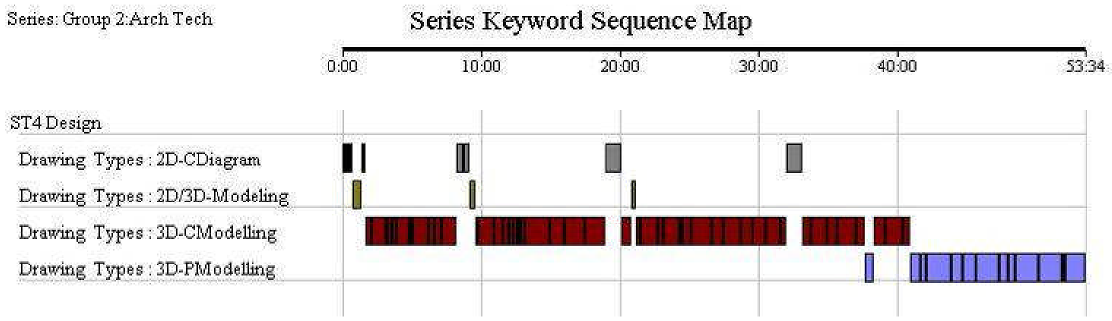


Figure 9-15 Drawing Process of ST4

The relationship between these drawings was also sequential, as SA2 considered the functional spatial aspects of the design problem - through 2D diagram- to reach a satisfied layout for the new design. He then moved completely to 3D mode to work on the conceptual aspects where he made conceptual changes and worked between 3D-CM and 3D-PM in the final phases to focus on the presentational aspect of the model towards the end of the design process.

SA3's single CAAD program based protocol, used AutoCAD exclusively. The student created drawings including four types: two-dimensional diagrams (2D-CD), two-dimensional conceptual elevation (2D-CE), 2D/3D transitional mode and three-dimensional presentation model (3D-PM). The relationship between these drawings was also sequential, as SA3 considered the functional spatial aspects of the design problem - through 2D diagram- to reach a satisfied layout for the new design for an extensive period of time (approximately 50 minutes). He then drew an elevation section simply because the proposed 2D building was elevated, so he needed information to convey this conceptual facet, which helped him to define the columns location from 2D-CE to be embedded in 2D-CD.

Following this, he moved from 2D to 3D mode to work on applying the conceptual aspects at a detailed level in 3D-PM. In the latter phases, a back and forth pattern was identified between 3D-PM, 2D-CE and 2D-CD. However, the final phase focus was 3D-PM which conveys the presentational aspect of the model towards the end of the design process.

SA4's single CAAD program based protocol, used SketchUp exclusively. The created drawings that were used extensively consist of three types: two-dimensional diagrams (2D-CD), three-dimensional conceptual model (3D-CM), concluding with three-dimensional presentation model (3D-PM). In this case, engagement was mainly in 3D-CM and 3D-PM.

Observing the students' engagement in the drawing process (whether by drawing act or visual engagement), shown in Figures 9-12, 13, 14, 15 and 9-16, suggests that the participant engages in one type of drawing and mode (2D/3D) for a series of segments whereby he uses one type of drawing for exploring different design micro strategies while considering more than one level of abstraction.

Comparing the drawing type was used at the early phases of the design process showing that the participants who used AutoCAD program (SA1, SA2 and ST3) had used the traditional method of using 2D diagrams in solving the spatial functional requirements for the design task. This is compared with the fourth case (ST4), who used SketchUp extensively, employing 2D diagrams interchangeably with 2D/3D and solving spatial functional design requirements, mainly in 3D modelling. While using 2D he was engaged in verbal mode (speaking) rather than visual mode (drawing) of the protocol and when he started actively addressing the design issues, he was in 3D modelling. The same trend can be identified for the rest of his design process but he also addresses the presentational quality of the 3D model towards the end.

Comparing the drawing types that were used in the early phases of the design process for all participating students suggests that the participants that used AutoCAD program (SA1, SA2 and ST3) from the beginning of the design process had used familiar methods (training) that is methods they have been taught, in solving the spatial functional requirements. These methods can be described as exploring spatial and functional requirements in 2D diagrams, aimed at developing a layout for the building. This consisted of proposing a layout between the trees, then drawing the spaces to understand relationship and property in relation to the context (layout and the site). These participants reflect a holistic approach in dealing with the conceptual aspect of design functional/spatial requirements and /or problem solving.

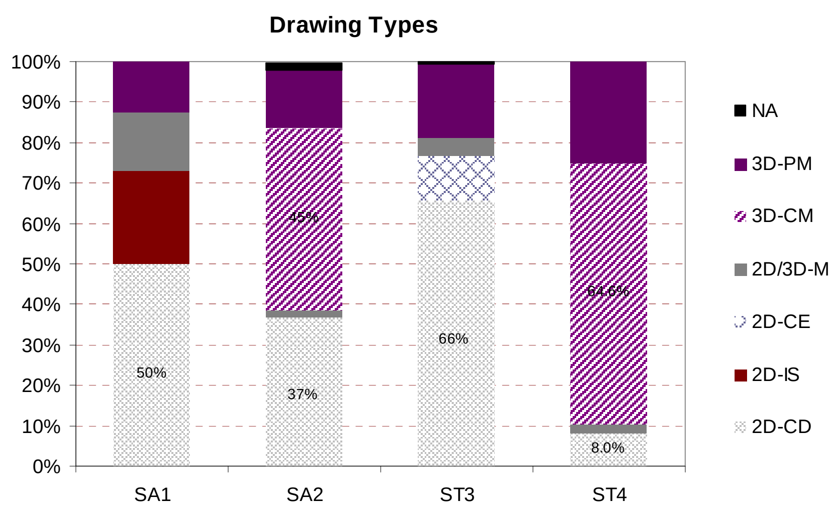


Figure 9-16 The percentage of time spent in drawing a certain drawing.

Participant (ST4) used SketchUp extensively. As a result the early phases of his drawing activity revealed an unfamiliar method in solving design spatial and functional requirements. This was illustrated in two ways: he approached the brief by creating separate volumetric spaces, mainly in 3D, yet he engaged in 2D diagrams in a secondary mode of externalisation, that is viewing actions and verbal ideas without documentation. In contrast to the other cases, this case reflects an atomistic approach to the early phase of the design process.

In summarising this section (Figure 9-16) the following points are made:

1- All cases have addressed the presentational quality of the 3D model towards the end of the design process.

2- There was a transitional mode from one drawing to the other. This can be seen in SA1, SA2 and ST3. With ST4 an interchangeable mode was more evident. Simultaneously, observing drawing types in 10 minute intervals in all cases shows that in SA1, SA2 and ST3, each interval was dedicated primarily to one drawing type and rarely with more than one drawing. However, ST4's intervals were mainly dedicated to types of drawing using three types successively, but rarely sticking to one drawing type.

3- The primary mode was 2D-CD for most of the participants. The most popular secondary mode was 3D-CM in two of the participants (phase after early 2D-CD and both with CAAD program SketchUp), the final mode was 3D-PM, again all the participants ended with this kind of drawing. Consulting external information in drawing terminology involved two types of drawing: 2D-IS and 2D-IE. The purpose for drawing them was to answer a question or to propose one conceptual aspect for one of its elements for example columns (ST3) and roof wedges angle (SA1).

4- There was no instance recorded of going back to the 2D diagram to modify it conceptually after advancing to 3D modelling in cases SA1, SA2 and ST3. This reflects a different method in solving the spatial functional requirements.

All participants engaged in 2D conceptual diagramming (CD) at the beginning and in 3D presentational modelling (PM) at the final phases of problem solving. In-between, the drawings that were made varied in their purpose from being informative to being conceptual.

9.4.3 2D and 3D mode of engagement

Classifying the drawing types into 2D, 2D/3D and 3D, in figure 9-17, two participants spent more time designing in 2D drawings and less time designing in 3D drawing. The design approach of these students can be seen as a 2D based CAAD approach. On the other hand, participant ST4 spent most of the time designing in 3D mode, which can be seen as a 3D based CAAD approach, with SA2 being classified as a 2D/3D based CAAD approach.

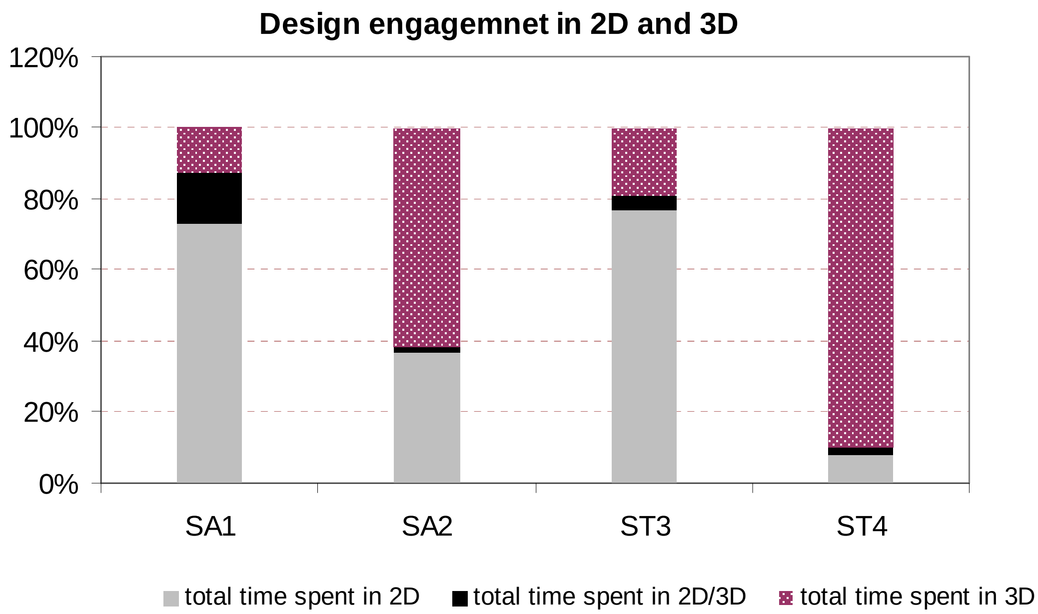


Figure 9-17 design engagement in 2D and 3D

articipants SA1 and ST3 spent most of the design process engaging in 2D visual activity rather than 3D visual activity (reading off information, drawing, referring to given or new parts, and inspecting given or new parts) with higher instances of 2D/3D engagement. 2D/3D engagement acts as an intermediary state to shift visual /conceptual information from a lower level of abstraction (primarily in 2D) to a higher level of abstraction (in 3D) and 3D construction. Except in the case of SA2, the transition was shorter than in the other participants, mainly because of the student's strategic design approach: design problem solving occurred in 2D and moved to 3D for further modifications and changes (a more parallel process of construction and conception). In the case of ST4, the participant's 3D approach is also considered a parallel approach to thinking and constructing the design proposal.

At the general level of analysis, the segments were analysed and described in terms of frequency, total number, and intervals. The following sections reveal how the design process content was analysed in terms of the coding schemes.

9.5 Design Process Oriented Coding

This section presents the first main coding scheme (discussed and modified in section 5.2.5); design micro strategies. Each segment is coded with one code of design micro strategy. The distribution of design actions 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 (near the beginning or near the end of the design session) in relation to design context (problem, drawing type and CAAD program). Consequently, the results (of encoding) also contribute to our understanding of the anatomy of the design (protocol) activity and the identified phases of intensiveness.

The design session segments were coded using the process oriented coding scheme and studied qualitatively and quantitatively accordingly. Through Transana's platform, the total time spent in each micro-strategy (design process codes) was documented. Hence, the total time for each strategy can be detected and compared throughout the four protocols. As such, the duration (time) 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.

9.5.1 The phases of the design process

Based on the chosen keywords (codes), Transana creates a series' keyword sequence map, where coded segments are shown along the process time line as coloured/shaded stripes, which can be read in relation to the time scale; the length of the strip indicates how long the participant has spent on a specific strategy. This was useful in identifying some of the emergent patterns in the coded protocols. Figures 9-18, 19, 20 and 21 present each student design process along the design timeline for the same design problem (a gathering space). All the segments (clips) are coded with only one code, thus every segment refers to one design strategy. The success of the design process was measured by the number of shifts of intention, as previously justified in section 4.4 and 5.6.1, which is assessed according to the number of segments and content codes.

In this respect, four phases were analytically identified in the case of SA1. That is to say SA1's design strategic cycles were traced by moving from one micro strategy to a different micro strategy, or using the same micro strategy but considering a different part of the design proposition (the transition between any two successive segments attached to different codes or same code). The first phase lasted about 21 minutes, which was identified as the richest and the most extensive in terms of variation of micro strategies and number of transitions. However, its continuity was interrupted by the student as he explained "*thinking to start putting in text; menial kind of tasks to bring us the chance to think about other things, it is almost like a break from my brain*". This was coded as a CAAD based explicit strategy (lasting for 2:16 minutes). The second phase lasted about 5 minutes and 26 seconds, while he was engaged in rapid cycles of modifying the proposal, clarifying and analysing the proposed solution (structure, entrance details to clarify the entrance as invitatory by tilting the roof). The third phase lasted for another 13 minutes of gathering information about the required height, which was achieved mainly through drawing a section to consult external information regarding his intention (tilting the roof). This was then followed by the final phase of applying all the previous moves and the gathered information to construct the design in 3D. In relation to the former phases, this was identified as a minor conceptual phase.

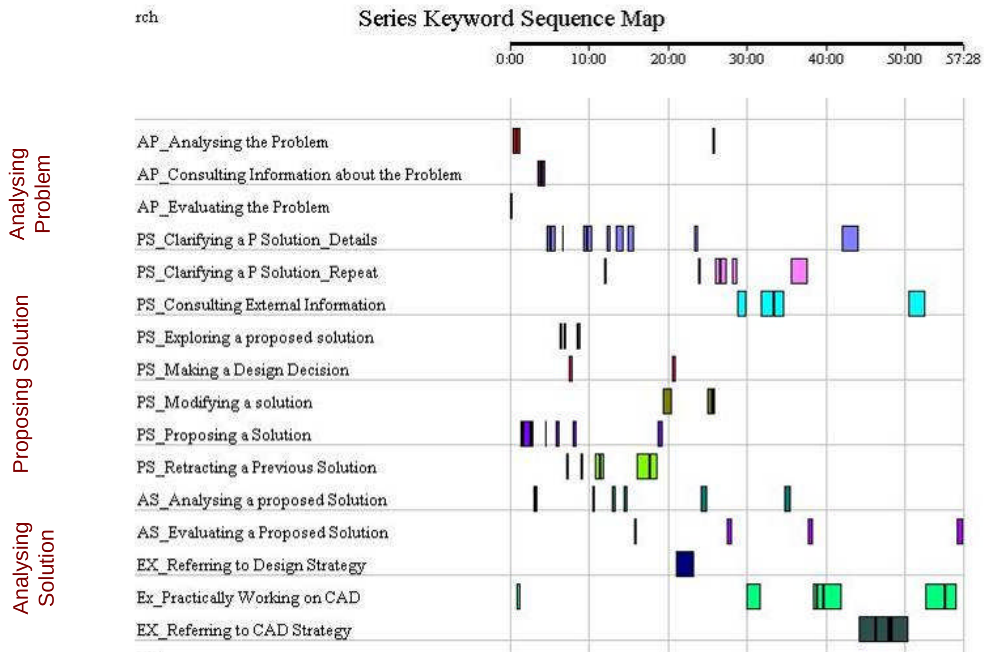


Figure 9-18 SA1 design micro strategies along the design session timeline.

As shown in Figure 9-18, SA1's design process starts by evaluating the design problem in context (site/ CAAD drawing) and analysing the problem in relation to the design brief requirements. He then moves from the problem space to propose a partial solution regarding the shape of the site layout and again starts to analyse the given problem with respect to the changes he has made. Afterwards, he engages in proposing a solution for an extensive period of time; cycling between a number of proposing solution (PS) micro strategies, for example clarifying a solution by adding details or by exploring a proposed solution graphically which enabled him to decide the functional and spatial layout of the proposed building. This is followed by another period of cycling between proposal of a solution and analysis. He ends this phase by making a design decision regarding the building structure. In general, in the case of SA1 the prevalent trend of micro strategies transition was between proposing a solution and analysing it for most of the design process.

In the case of SA2 multi-CAAD protocol (AutoCAD and SketchUp), whilst observing SA2's design process in Figure 9-19, in terms of design micro strategies and cycles, the results showed that the process went smoothly despite the switch from AutoCAD to SketchUp. It is, however, a three phased process.

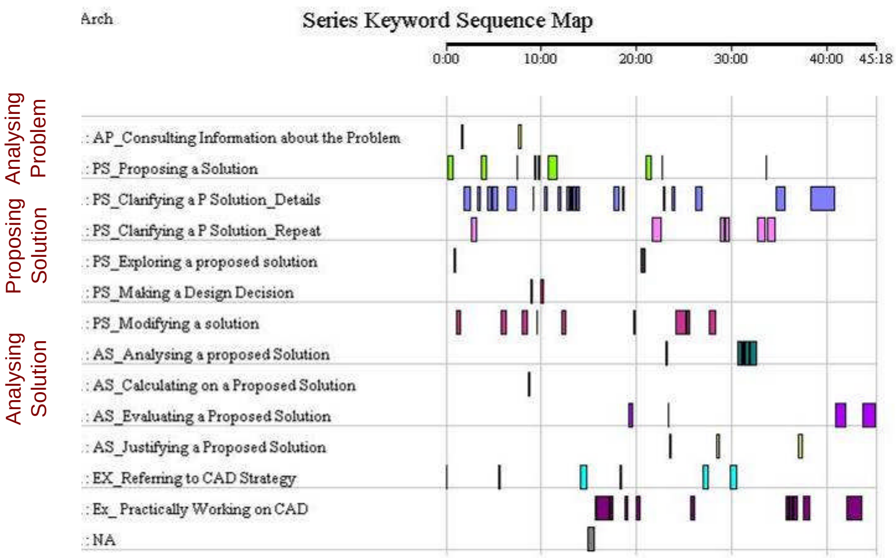


Figure 9-19 SA2 Design micro strategies along the design session timeline.

Tracing SA2's design strategic cycles showed that the first phase lasted for about 14 minutes, which was identified as one of the rich and extensive phases, in terms of micro strategies' variation and number of transitions. Obviously, the student was engaged in proposing a solution more than any other analytical strategy while he was engaged in 2D to propose a spatial functional layout.

A transitional gap was then noted when the student moved to the SketchUp program (which lasted for 3 minutes and 30 seconds) between the first conceptual phase and the succeeding ones. The second phase started (at 00:17:39) when the student said "*how to look from the outside*" which he wanted to explore in 3D mode (one reason to shift into SketchUp as it is considered to be a 3D package). Although he was in 2D mode, he mentioned a conceptual design criterion (heights in relation to different uses). His verbal context has set some of the 3D features of the 2D.

The second phase lasted for about 23 minutes and 16 seconds. During that time SA2 was engaged in rapid cycles of proposing solution micro strategies; clarifying by adding detail, evaluating, modifying and analysing the proposed solution. This was followed by the final phase of considering the design building on a detailed level of visualisation to explore the design massing by lighting/shading as one of CAAD's automated effects in 3D mode. In relation to the former phases, this is identified as a minor conceptual phase.

This participant provides an example of a "CAAD based-aha moment" (Akin and Akin 1996) or describes sudden insights - seeing something he did not intend to draw or create - and illustrates the automated intersection between the created volumes in 3D (SketchUp) which made him pause, think and evaluate it. Instead of correcting the resulting image, he continued analysing it and went on to justify the image in terms of the conceptual framework of his design to confirm his previous intentions.

> Seg 53 "*(0:23:18.4) now I just come across that without thinking about it but from the way the software works it made me think".*

Although the process went smoothly, two smaller-gaps were identified which intersect with CAAD explicit strategy (design medium effect) coded stripes. (This will be investigated in section 9.6.5).

The early phase of the session (in the first 14 minutes) is where designing is carried out using 2D AutoCAD drawings, whereas the other two zones occur at the latter phases of the process and were carried out using 3D SketchUp modelling.

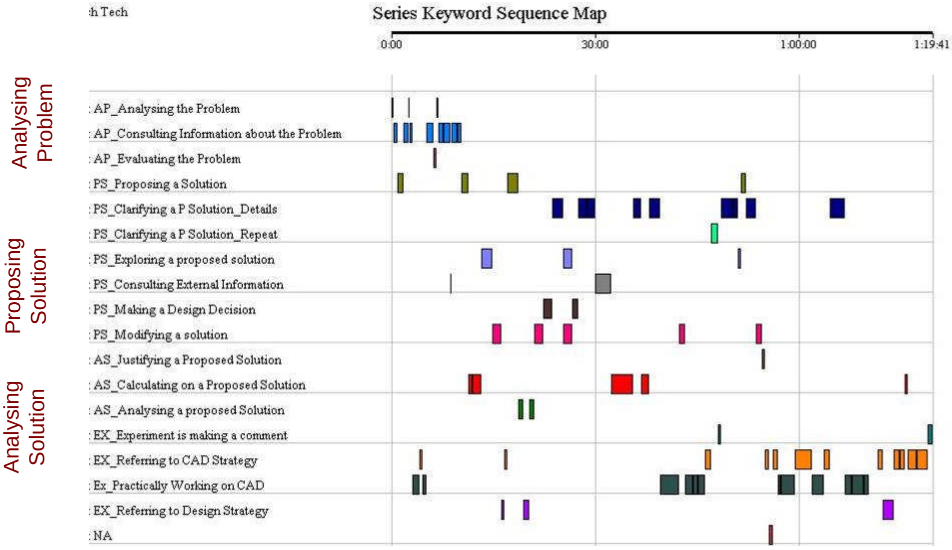


Figure 9-20 ST3 Design micro strategies along the design session timeline.

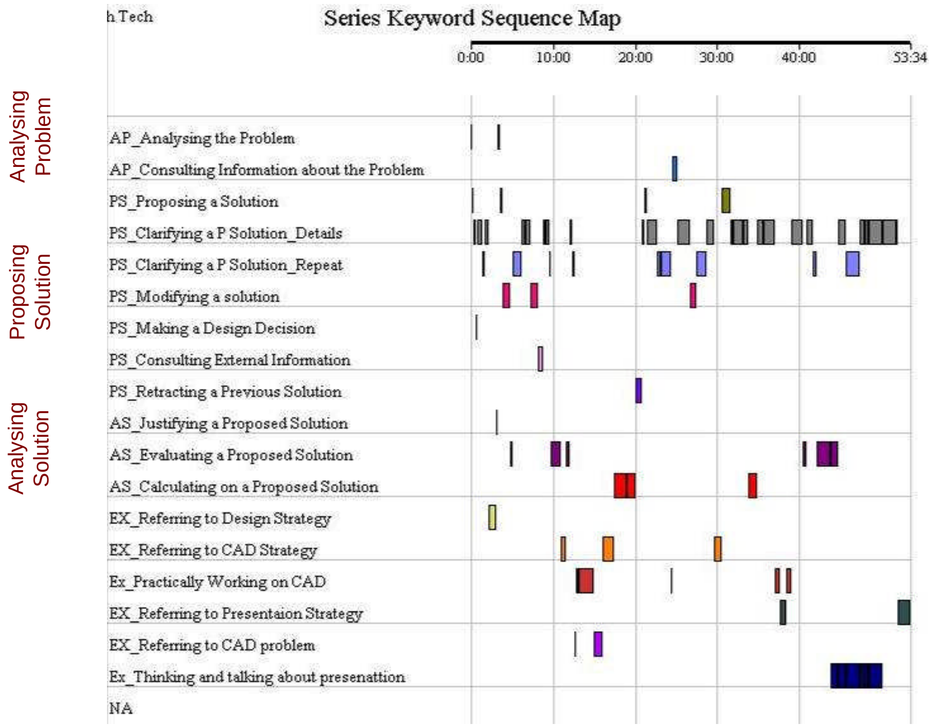


Figure 9-21 ST4 Design micro strategies along the design session timeline.

In the case of ST3's single CAAD design protocol where the coding of SA3's design process (shown in Figure 9-20) is observed in terms of design micro strategies and cycles, the student's micro strategies seem more stretched along the time line as this was the longest protocol session. It is, however, a three-phased process.

Tracing ST3 design strategic cycles showed that the first phase lasted for about 29:57 minutes. This phase was considered lengthy and was identified as the most extensive phase, in terms of micro strategies variation and number of transitions (number and rate). At the beginning, the student was engaged in analysing the problem and consulting information about the problem and proposing a solution more than any other design strategy, while he was engaged in 2D to propose a building layout for the site and a spatial functional layout.

The second phase lasted for about 23 minutes and 16 seconds. During that time ST3 was engaged in rapid cycles of proposing solution micro strategies; clarifying by adding detail, evaluating, modifying and analysing the proposed solution. This was followed by the final phase of considering the design building on a detailed level of visualisation to explore the design massing by lighting/shading as one of CAAD's automated effects in 3D mode. In relation to the former phases, this is identified as a minor conceptual phase.

In general, ST3's design strategy shows that the participant's praxis followed traditional methods in problem solving. This was illustrated in proposing a rough layout for the new building, to drawing the brief requirements graphically through bubble diagram (exploring the relationship between the different uses), to utilising the same bubbles within specific sized spaces. These spaces were then treated as zones because the student's spatial idea was to have open plan dining areas, rather than separated areas. In the next step, he moves the resulting special layout to the site and modifies the two in relation to the spaces and the surroundings (site constraint: tree) by embracing the tree within the final layout. He then moves on to a detailed level of the building to look at the structural aspect of it and to locate the columns that were proposed in the elevation to be embedded in the plan. The final phase consisted mainly of modelling the previous decisions: the emphasis on conceptual clarification rather than conceptual change or modification.

In the case of ST4 single CAAD (SketchUp) design protocol (shown in figure 9-21) the participant's design strategic cycles showed that the first phase continued for about 12:39 minutes, which was identified as the richest and the most extensive phase with respect to the micro strategies' variation and number of transitions. The student was engaged in analysing the design problem, proposing a solution and clarifying a solution more than any other analytical strategy while he was engaged in 3D to propose a "volumetric" spatial functional layout.

Afterwards, a CAAD practical engagement phase took place when the student noticed incorrectly-drawn elements (lines were unintentionally created by the software – technical). During this phase, problem-solving took about 4 minutes. The succeeding phase was noted when the student engaged in labelling the previously created forms in SketchUp terms. The second phase started at (00:16:00) when the student started to calculate a proposed solution, and after consulting the brief requirements, he decided to retract the first proposition which he'd initiated before experiencing the problem of CAAD surfaces.

He then concluded that a better functional proposition would be achievable if the kitchen was near the serving area which led him to suggest "*if we can.. combine both the kitchen and dining area in one*". Checking the area made him retract the volume he created for the kitchen and instead of having two zones (areas) within that same form, he created two separate forms (bigger volumes) for the kitchen and serving area. He could modify the volumetric form instead of retracting the whole drawing. This shows how designing in CAAD can change the student's approach from familiar to unfamiliar, and influence his design decisions. A simple example was starting with 3D rather than 2D, as shown in Table 9-7.

Table 9-7 ST4 extracts

Time stamp	Transcript
(0:20:38.5)	"*So I go back ... I know I did a lot of work to get here. So I go back and create this one area. I can combine the serving kitchen area and the kitchen area as one. If I put the kitchen area to the back and the serving area to the front it will make much more logical sense."*
(0:21:26.7)	*"so I [will] create a volume for the kitchen. I think we'll create something here, so I'll create a volume for it. I create a volume of the serving area (0:21:48.8) make a group first 0:21:55.0 can name it as 'service area' with a fifteen- twenty metre squared area.[combing zoning and volume creation]*
(0:22:12.2)	*"So I have created this as the serving area, and this square here I'll create as the kitchen. I'll group it together. Let's call it the kitchen. Ok."*

Then the student started to work on the model as one entity and part of the preparation for adding texture and lower level detail; (windows and doors, position, size and texture) this activity lasted for 15 minutes. Afterwards, he felt that the design was ready for communication and he would like to see it in context (main site drawing).

9.5.2 Design process coding percentages

In this section, the focus of analysis is the design micro strategies codes and percentages to answer whether using CAAD in design (condition) would have certain consequences on the design micro strategies cycles. This is documented by the total time that a participant spent in designing in relation to what was considered one of the major categories of the coding scheme; *design problem analysis (analysis), proposing a solution* (*synthesis*) and *analysing the solution (evaluation).*

The encoded results of the design process (that were presented in Figures 18-21) were tabulated and an activity distribution was mapped for each sub action of the coding scheme for further comparison. From tabulating Transana's summary of coded segments (counting values) in Excel through charts, one can see that there are differences in the occurrence of design micro-strategies and the total time spent in each category. This is calculated as a percentage of the total time that each participant spent in designing. Accordingly, the time spent on every sub action is summed up for the whole design session and presented as a percentage.

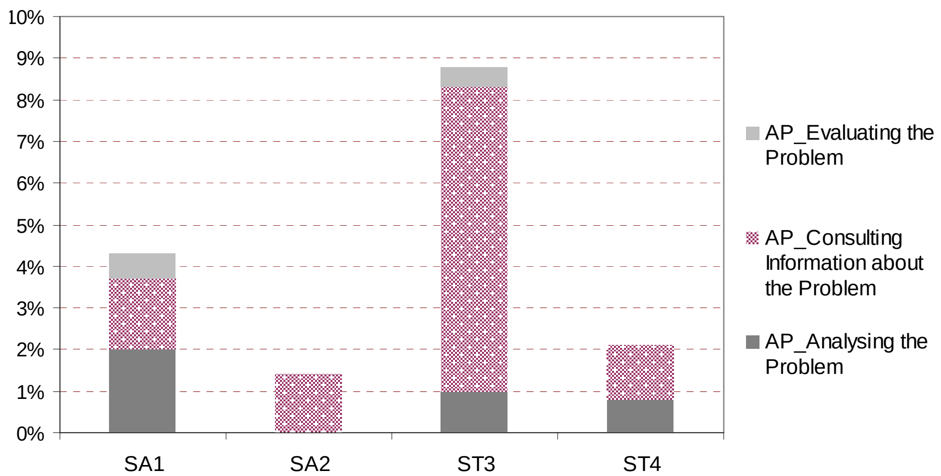


Figure 9-22 Design micro strategies (Analysing a Problem) of all participants.

Next, the breakdown of analysing the design problem micro strategies is presented for all students, as shown in Figure 9-22. ST3 and ST4 spent similar amounts of time (1%, 0.8%) on analysing the design problem by making calculations of expected behaviour, whereas SA1 spent 2% of the design session duration on this activity.

All of the students (SA1, SA2, ST3, and ST4) approached the design problem by consulting information, that is using the information that is given in the brief. ST3 spent more time (7.3%) than the others (SA1: 1.7%, SA2: 1.4%, ST4: 1.3%). This difference arose mainly because SA3's approach was different. He used this information to draw what he read in the brief in order to explore it graphically before proposing a solution. In a process of functional spatial design relations, he drew a rough bubble diagram, followed by drawing the proposed sizes for the required spaces (another example of the use of familiar traditional methods). The rest explored this aspect while proposing a solution (SA2, ST4) or before proposing each partial solution (SA1). SA1 and ST3 spent 1.7% and 0.5%, respectively, on evaluating the design problem with respect to design constraints, requirement (trees in both protocols).

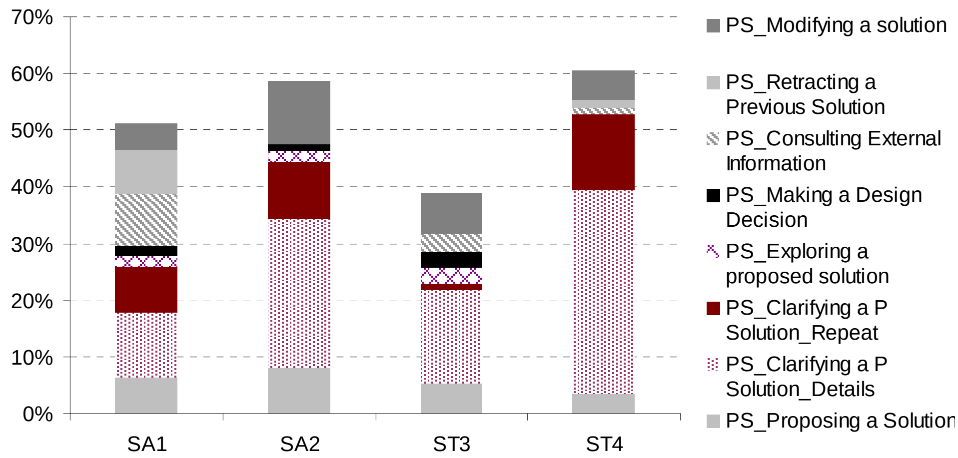


Figure 9-23 Design micro strategies (Proposing a Solution) of all participants.

A breakdown of proposing the design solution (PS) micro strategies are presented for all students as shown in Figure 9-23. Proposing a solution or partial solution occurs either verbally through memory retrieval, or visually through perceptual stimulus. Thus, proposing a solution does not necessarily occur through graphical externalisation and exploration: instead, it is achieved by clarifying a solution.

All of the students (SA1, SA2, ST3, and ST4) approached a tentative design by proposing a solution, 6%, 8%, 5.4% and 3.5% respectively. They spent considerable amounts of time clarifying the proposed solution either by adding detail, or repeating a previously designed detail or element. SA1 and ST3 spent similar amounts of time (20% and 19.6%) of the total duration on clarifying the design proposal (SA1 spent 12% on design elaboration by detail plus 8% by repeat and ST3 spent 18.4% elaborating the design by detail and spent 1.2 % by repeat). SA2 spent significantly more time 36% (26%+10%) of the design duration and ST4 spent 49% of the design duration on elaborating the design, either by adding a detailed proposition (35.8%) or by repeating a previously elaborated detail (13.5%). As a general tendency, all students spent higher percentages of time on clarifying the design by adding details rather than repeating already designed elements. Even when they used the same object, they drew it again rather than copying it, which they are more likely to do (for purposes of ease) with a computerised medium.

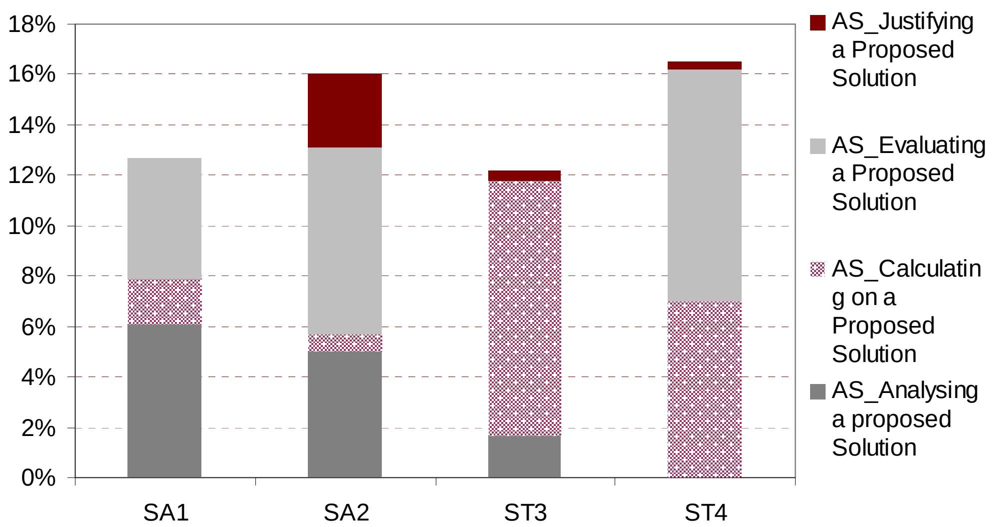


Figure 9-24 Design micro strategies (Analysing a Solution) of all participants.

SA1, SA2 and ST3 spent a lesser portion of time on exploring the proposed solution (2%, 2%, 2.7%) and making design decisions (2%, 1% and 2.8%). SA1 spent 9% of the total duration on consulting external information, 8% on retracting design proposals or partial proposals, and 5% on modifying the proposed solution. SA2 spent 11% on modifying the proposed solution. ST3 spent 1% and 1.4% and 5.2% on consulting external information, retracting design proposals and modifying the proposed solution. ST4 spent 3.4%, 2.3% and 7%, respectively. A breakdown of analysing the design solution (AS) micro strategies is presented for all students, in Figure 9-24.

SA1 and SA2 spent 6% and 5% respectively, of the total duration on analysing the proposed solution. ST3 spent 1.7%. ST3 and ST4 spent the same amount of time (7.5% and 7%) on analysing the design proposal by calculating it. SA1 and SA2 spent less time (2% and 1%) which may be related to prior knowledge and experience.

SA1, SA2 and ST4 spent a relatively low percentage of time (5%, 7% and 9.2%) on analysing the design proposal by evaluating it. SA2 spent 3% of the total duration in justifying the design proposal which has a direct connection to the CAAD "new insight" moment that he experienced while designing with CAAD (SketchUp) whilst ST3 and ST4 spent minor percentages of time justifying the proposal. Figure 9-24 shows that the design micro strategies were distributed irregularly. Clarifying a proposed solution, either by adding more details or by repeating a previously clarified solution (36%) occupied the largest portion of the session duration. Modifying a solution (11%), proposing a solution (8%), evaluating a proposed solution (7%) and analysing a proposed solution (5%) occupied a smaller portion of the total duration. Strategies like consulting information about the problem (1%) and making a design decision (1%) calculating on a proposed solution (1%), exploring a proposed solution (2%) and justifying a proposed solution (3%) occupied the smallest portion of the design duration.

The following section presents a detailed breakdown of what, which is summarised in Figure 9-25. Individual differences are apparent and highlighted. A simple summary would not be appropriate since it would mask these individual differences.

9.5.3 Design micro strategies summary

In summing up the strategies for all participants, Figure 9-25 presents the general categories of the micro strategies. Two of the cases, SA2 and ST4, bear a resemblance in the general categorical percentages of the total time spent on a certain category. Most of the protocol duration was spent on proposing a design solution (59% and 60.5%), spending 22% and 20.7%, respectively, of that duration on analysing the design solution, with only 1.4% and 2.1% respectively, of the duration spent on analysing the design problem. However, nearly a quarter (22% and 20.7% respectively) of the design protocol was spent on explicit strategies as they are concerned with codes other than the design process, that is CAAD working strategy, planning, difficulties and problems.

Having said that, the detailed analyses of SA2 and ST4 of the design micro strategies demonstrate the many differences that each student exhibited during the design protocol. This makes the modelling of a design process on a lower level of detail difficult, if not impossible.

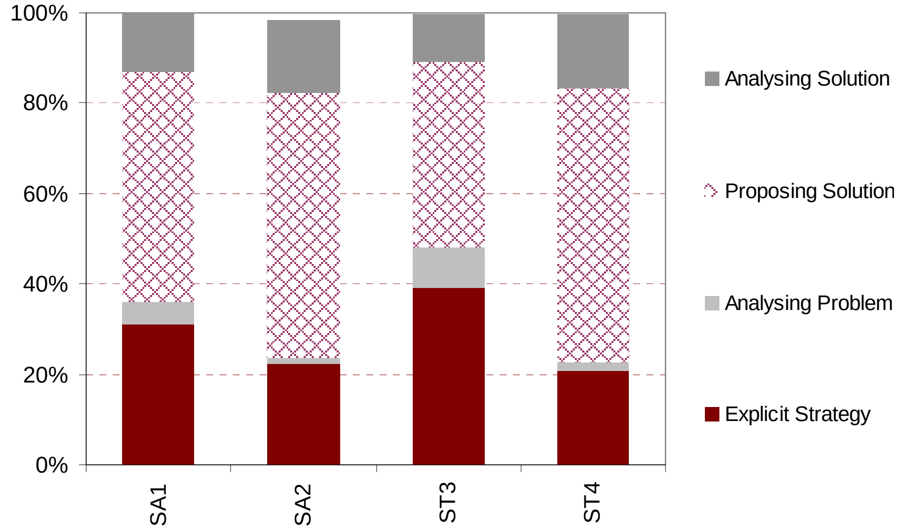


Figure 9-25 Design process micro-strategies as a percentage of the elapsed time.

On the other hand, SA1 and ST3 are different (to SA2 and ST4). Most of the design protocol duration was spent on proposing a design solution (51% and 40.9%), spending 13% and 9.6% respectively, of the duration on analysing the design solution, with only 4.3% and 8.8% respectively, of the time spent on analysing the design problem. However, more than quarter (32%, 39.8% respectively) of the design protocol was spent on explicit strategies, as they were concerned with codes other than the design process, that is CAAD working strategy, planning, difficulties, and problems therefore illustrating that individuals are very different. Summary overviews would not have revealed these individual differences.

In general, these results show that the majority of the time students spent designing in CAAD was based on proposing a solution more than any other design solving behaviour.

9.5.4 Level of abstraction

The main objective of adapting this coding scheme was to ascertain whether the CAAD medium would affect the level of abstraction in a certain way, that is whether using CAAD in conception would prompt one level of abstraction, with an emphasis on detailed design. Thus, Transana's keyword sequence maps were created and observed as a separate coding scheme and in relation to the other schemes.

The segment code 0 indicates that the participant is considering the proposed design in relation to the whole site (circulation, orientation, views, surrounding buildings, etc.). In terms of CAAD use in the early phases, this level of abstraction was represented mostly by three external representations: gesture, inspecting and referring to the site drawing, which in turn affected the students' level of consideration by physically engaging in drawing acts.

In figure 9-26, each level of abstraction is shown in relation to the whole design process for each participant and refers to the level of abstraction the student is considering at any point in the process for each segment. Observing the sequence of the level of abstraction the students engaged in through the process shows two things: (1) the students were able to navigate through the different levels without restricting their vision to a certain level, and (2) the students were able to think of the overall design (Level 1: considering the site layout constraints and opportunities) and at the same time think of more design-specific aspects (Level 2 considering the spatial elements of the design layout and its relation to the site and the surrounding features) while progressing into considering detailed aspects of either levels 3 or 4, which would influence the final design or restrict it.

From the process point of view, the patterns observed in Figure 9-26, reflect a reduced amount of change in the level of abstraction for each student. Also, many instances were observed where the student was considering the same level of abstraction over a number of successive segments (chunks of abstraction).

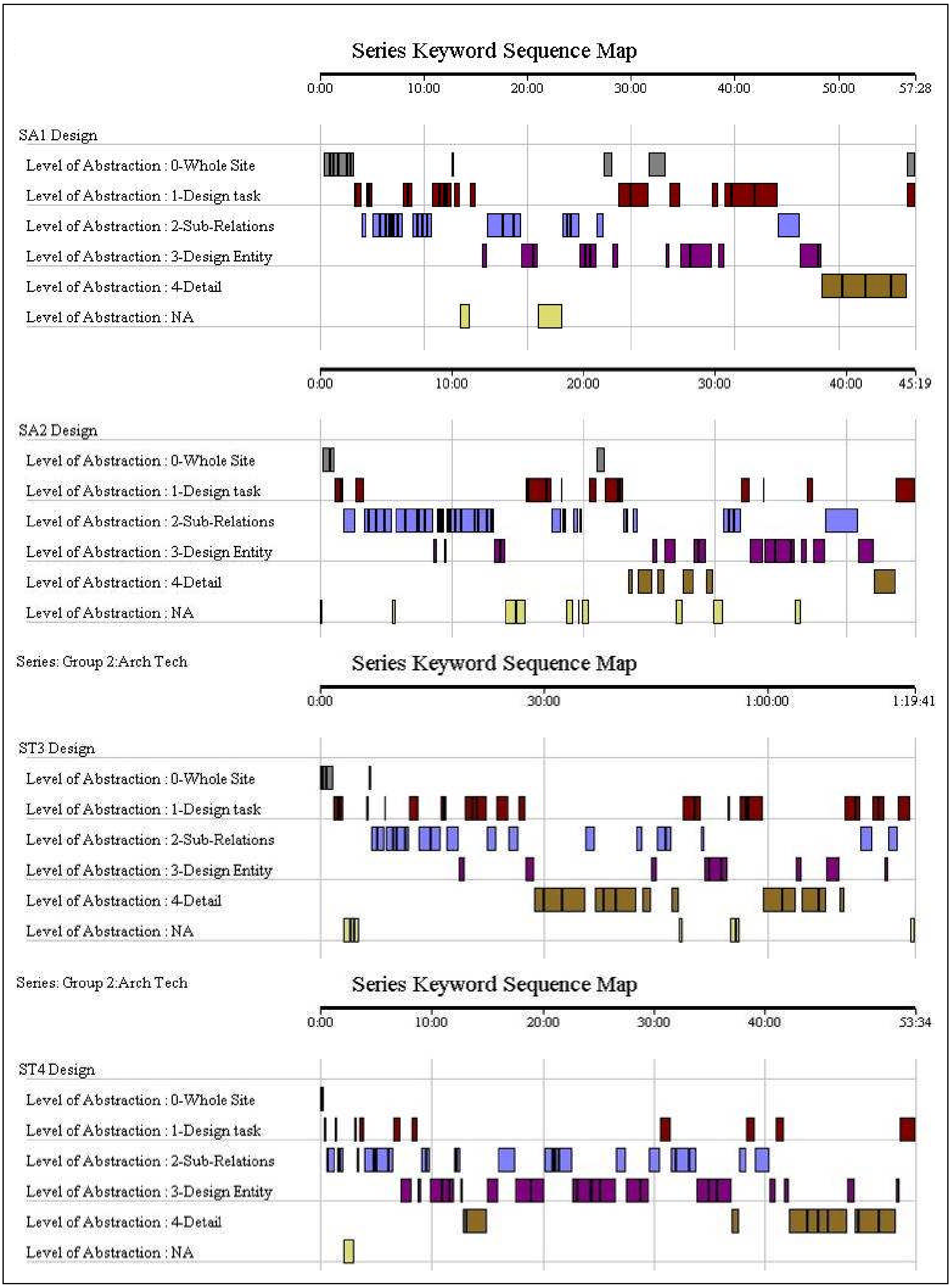


Figure 9-26 The level of abstraction along the design process timeline.

However, these chunks had sharp turns either downwards or upwards. The prevalent pattern was downwards, that is from the more abstract level (overall) to the more detailed level and back to upper levels of abstraction.

As shown in figure 9-26, on a basis of 10 minute intervals, participants considered a minimum of 2 to 3 levels and rarely considered the design on 5 levels of abstraction. It also shows that to allow the consideration of the design at a certain level, more than one segment or several segments may be required.

The four participants showed hierarchical transition in their design processes, which correlates with design decisions structure (conceptual structure) made at the time of consideration to these levels. The participants mainly considered the design problem at the beginning of the design process at Level 0 (whole site) and evaluated the design problem in relation to the design proposal towards the end of the process at Level 1 (design layout).

Following this, the results of calculating the total time that a participant spends in designing in relation to the five levels of abstraction is presented in percentages. Figure 9-27 shows how much time each student spent on every level of abstraction as a percentage of the whole duration.

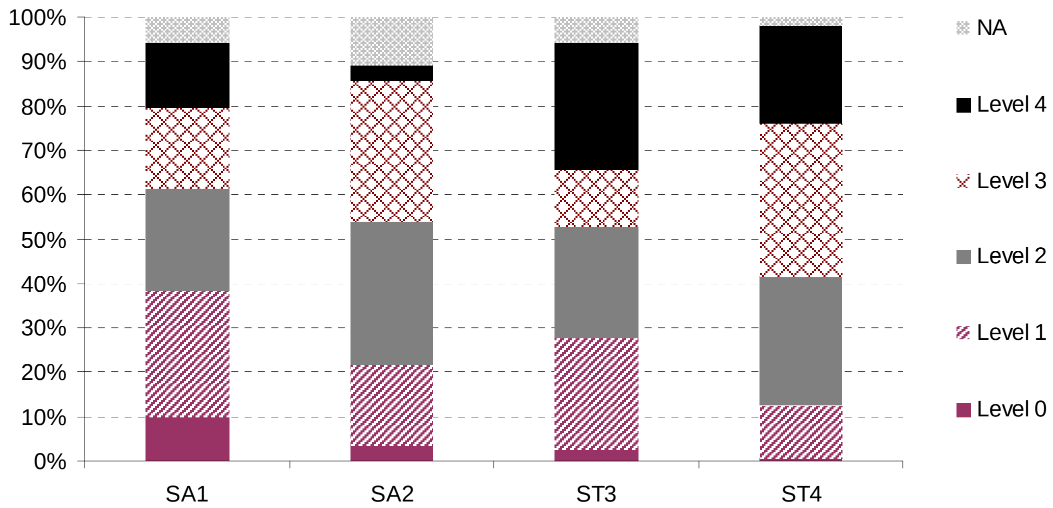


Figure 9-27 The levels of abstraction that each student considered while designing (the percentages table in Appendix G-5, p. 411).

SA1's design session time was distributed across the levels but was dominant on level 1, while spending relatively less time considering the design at levels 2, 3 and 4 consecutively. When compared to the other levels, the design consideration at level 0 was the shortest. SA2's design session time was spent considering the design on two dominant levels of abstraction, 2 and 3, while spending relatively less time on considering the design at level 1 and a very small portion of time on the two contrasting levels of 0 (whole) and 4 (detailed CAAD). ST3's design session time was spent considering the design on three dominant levels of abstraction: 4, 1 and 2 consecutively. ST3 spent less time considering the design at level 3 but very little time on level 0. ST4's design session time was distributed across the levels but was dominant on level 3, and level 2 consecutively while spending relatively less time considering the design at level 4 and 1 consecutively, with a limited abstraction scope on level 0.

These descriptions of time portions (percentages) and the levels lead to the following comparison and discussion: the average percentage of total time spent on detailed levels of abstraction (levels 3 and 4) is 41%, which is considerably higher than the average of time spent considering levels 0 (4%), 1 (21%) and 2 (27%). Nearly half of the average time of design sessions.

SA2 and ST4 spent most of the time considering the design at level 2 and 3. The participants' (except SA2) spent a relatively high amount of time on level 4 which is directly related to CAAD's shift of focus by physically engaging in drawing minor details with low level abstraction. The participants (except SA1) spent a relatively small amount of time on level 0. This shows that the students were able to compromise between two levels at the most and three levels in one case. 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.

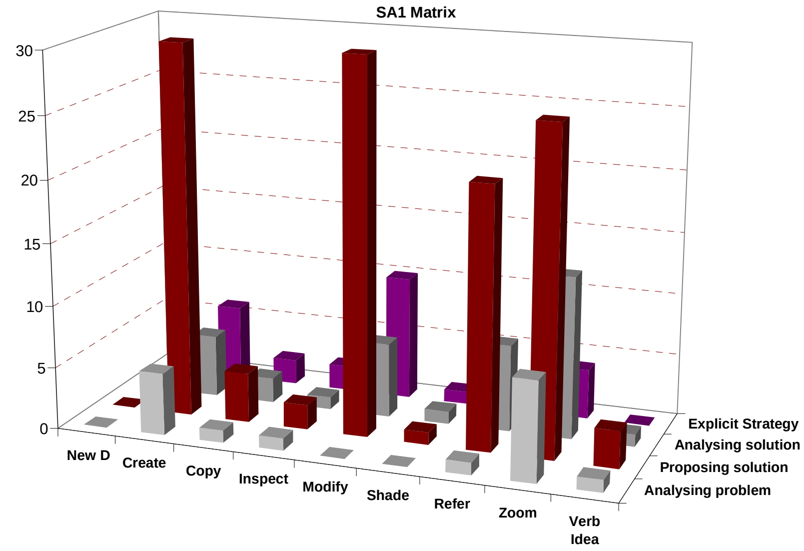
The students spent minimal time on considering the design problem on level 0 which could be contextualised in two ways. One way is to contextualise it in the light of the students' design micro strategies description in section 8.5.4 as it shows that all students spent a lower percentage of time on analysing 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 (externalisation). 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.

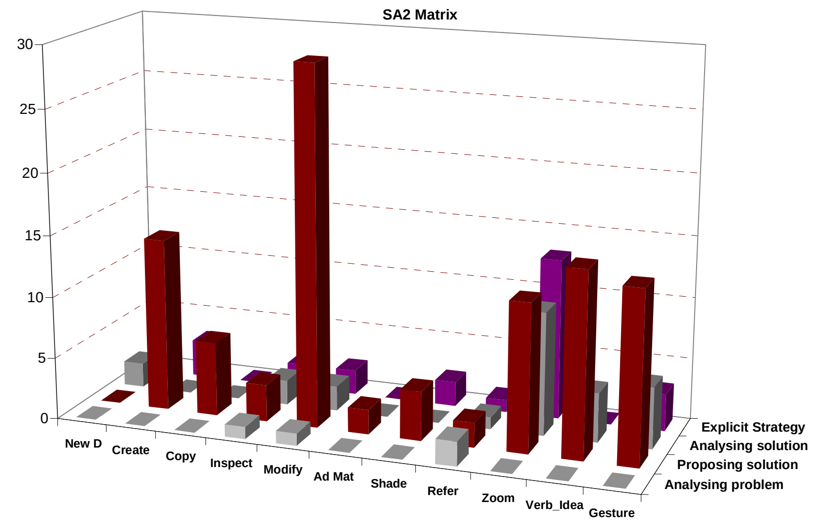
9.5.5 External representation occurrences

The Protocol Study in this thesis further investigated how design representational activities supported individual design processes in architectural design. The representations coding scheme (presented in section 5.5.1.d, and in Appendix D-3) was revised with respect to CAAD visual characteristics and 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 (which helped the student most to converse with CAAD as a visual medium). 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.

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 cases are presented in Figure 9.28. Each 3D bar (height) shows the number of occurrences of external representation in relation to design strategy.

In all cases, the students covered most of the external representations, 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. This was observed in all cases, shown in Figures 9-28 and 29.


SA1 Matrix
30
25
20
15
10
5
0
New D
Create
Copy
Inspect
Modify
Shade
Refer
Zoom
Verb Idea
Explicit Strategy
Analysing solution
Proposing solution
Analysing problem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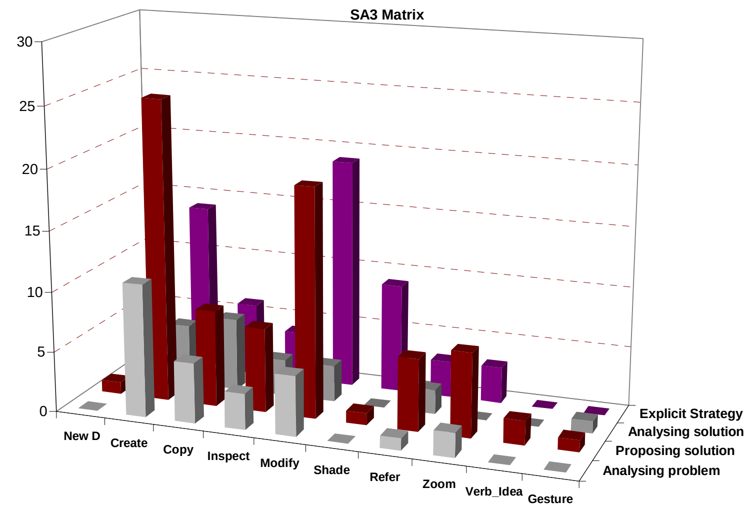
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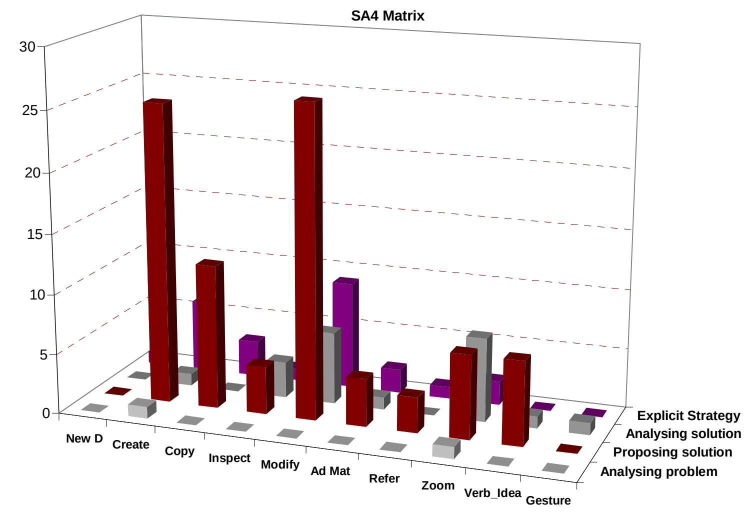


Figure 9-28 The matrices between main external representations activities and main design strategies (for a detailed breakthrough of ext. representations sub classes, graphs are provided in Appendix G6, p. 412).

Analysing the problem was intersected with the lowest number of external representations in cases SA1, SA2 and ST4. However, ST3 had the highest occurrence of create, modify, copy and zoom mainly because of his traditional approach, compared to the other segments where he had been engaged in graphical analysis rather than merely proposing solutions for the problem. The results of this also related to the relative time students spent in analysing the problem (see section 9.5.3).

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 in the case of ST3, shown in Figure 9-29. This is mainly because of his verbalising style as he 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 done (sub codes of explicit strategy), he is 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.

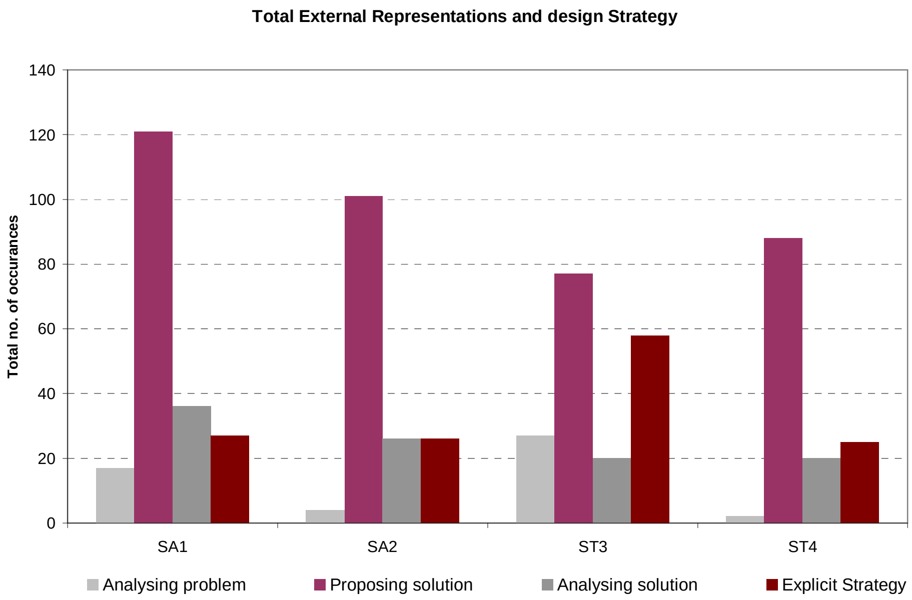


Figure 9-29 The matrices between external representations and design strategies.

Recalling drawing types and modes coding results suggests a reduction in pattern change compared to design process micro strategies, levels of abstraction and external representation. That is using the same drawing can be associated conceptually with various design micro strategies, levels of abstraction and external representations.

As a result of the analyses carried out in the previous sections (encoding the design process), the longer segments were likely to occur in the following conditions: while drawing in 3D mode and 3D presentational modelling, considering levels 3 and 4 of abstraction; that is working on the details of the proposed design or on details that are based on CAAD's way of drawing; using a design strategy of proposing a solution through clarifying the solution in detail (higher frequencies) or through repeat (lower frequencies). These were further categorised and presented in the next subsection.

9.5.6 Explicit strategy

In terms of the coding scheme that was applied for the design process (in section 5.6.1.b), some of the segments (clips) could not be coded under the process-oriented coding scheme (Gero and McNeil 1998; Tang 2001). Participants deviated from design to express or to explain CAAD's ways of doing things or even when they were faced with unexpected difficulties that were software based.

The deviation of the coding scheme was mainly concerned with the way CAAD had affected the design thinking process and verbalisation. *"The interpretation of a single phrase may be influenced by the context in which it appears."* (Gero and McNeil 1998 p.128). This was important in this study, although it depended on the verbalising style of the students and is related to CAAD's description and interaction with CAAD programs while designing. It is mainly found in the verbal data while the visual data provided the context of what was said. In design research studies, this was considered as outlying data that had nothing to do with theorising design or design collaboration.

Another perspective in which to view a CAAD design protocol, is in terms of continuity and engagement of the conceptual design process (this is also analysed in terms of the Linkography in the following section). CAAD's influence was observed through the four participants, as there were many instances where they explicitly mention CAAD. These were identified either via the student's verbalisation or CAAD representation, when the designer is explicitly referring to some aspects of CAAD use: presentation, problems and appraisal. "*These correspond to times when the designer is not directly engaging [in] the design task*." (Gero and McNeill p. 32). CAAD influence was subsequently coded primarily as another micro design strategy (code) for the designer (student) to be inferred as one type of influence that CAAD had brought to the conceptual design process. Consequently, these codes were classified into two levels of CAAD prime engagement. The first level of engagement was noted while the designer's sequential thinking was interrupted by a software-based error or an automated action, for example failing to zoom while designing. Such technical failure can affect the total time spent in active designing and breaks the continuity of conceptual cycles. Thus, the question is whether such interruption would relate or detach two successive thoughts in a sequence? In the case of SA2, many instances were found (18 clips /83). The following example illustrates three successive segments from participant SA2:

> *Seg. no. 44 (modified spatial properties), Seg. no. 45 (failed to zoom) and seg. no. 46 (extruded the space-display area-volume).*

From the analysis of these successive segments, we can conclude that the occurrence of this technical failure did interrupt the continuity of the design activity but when the failure was solved, the students worked on the same intention of the former segment. The second level was observed while the designer's level of abstraction was concerned with the design emergent properties on a detailed level of abstraction, for example assigning material, missing surfaces, which were either deleted or forgotten unintentionally; this time the level was that of practical engagement. In addition, knowing and learning how to draw the designer's expectation sometimes had to occur through trial and error, which can be related to CAAD's learning effect on the design process.

The longer segments that were coded as explicit strategies in all cases were either coded as Practically Working on CAAD (total frequency of 37 segments) or Referring to CAAD Strategy (total frequency of 24 segments). The former related to the way CAAD shifts conceptual intentions into operational fulfilment, whereas the latter refers to the verbalising style of the participating participant, when his verbalisation goes into describing the program or the way things should be done.

In the following section the identified interruptions are further investigated through design process linkographs, whereby re-structuring the design process is carried out with respect to connectedness and density clusters.

9.6 Linkography Results

In this section, the constructed linkographs of the protocol study four participants (SA1, SA2, ST3 and ST4) are presented in three subsections; a descriptive analysis of the linkographs is presented in the first subsection, the results of the design process linkographic coding and its quantitative measures in the second subsection. The final subsection summarises what has been analysed in relation to the content analysis of the protocol studies.
In other words, this section answers the following questions in the light of the analytical methods that were applied:

- In terms of the linkograph analysis, does using CAAD affect the design process productivity and continuity in terms of ideas association and links? Is it a linked process or fragmented, and if so why?
- What association can the ideas that were expressed during the protocol have?
- What are the qualitative and quantitative differences between the selected protocols?

The measures used to analyse the resultant linkographs were based on the analytical measures set in section 5.6.1.e. The results of the linkography method are presented in the same sequence of the design protocols in section (9.3), starting with SA1, SA2, ST3 and ST4.

9.6.1 Descriptive Analysis

Coding the design session in terms of design move(s) and moves association (Linkography), has revealed the structure of the conceptual/visual association. However, every case has revealed a different visual pattern that is related directly to the design protocol data and the development of the student's ideas. As shown in Figures 9-30, 31, 32, and 33.

Examining the resulting linkographs in Figures 9-30,31,32, and 33, showed many differences in the way the student's ideas were connected during design. These differences are presented on two levels of analyses: the first level was carried out using the quantitative method, by which linkograph is quantified by a number of measures, that is number of moves, link index (LI), critical moves (CM), percentages and link clusters. The other level was the conceptual content of the process from a methodological point of view, where concept or a partial idea of a concept is forming along the design process timeline (multi-modes of thinking). With respect to content analysis, linkograph is seen as a structure of associations among the design moves, that is coding the relationship between any two dependant design moves.

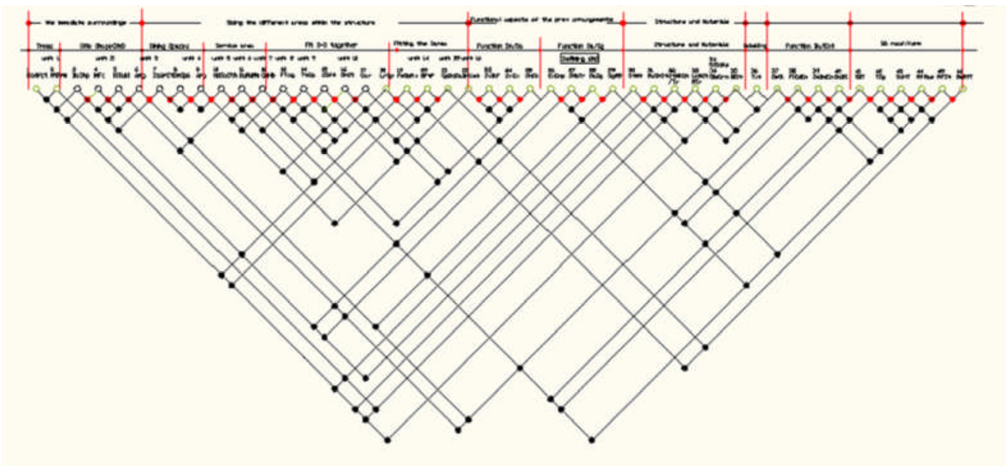


Figure 9-30 SA1 design process linkograph.

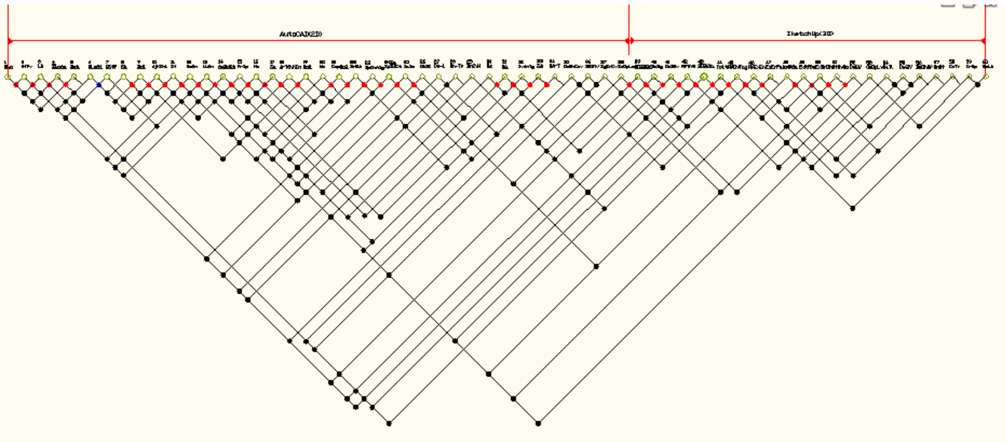


Figure 9-31 SA2 design process linkograph.

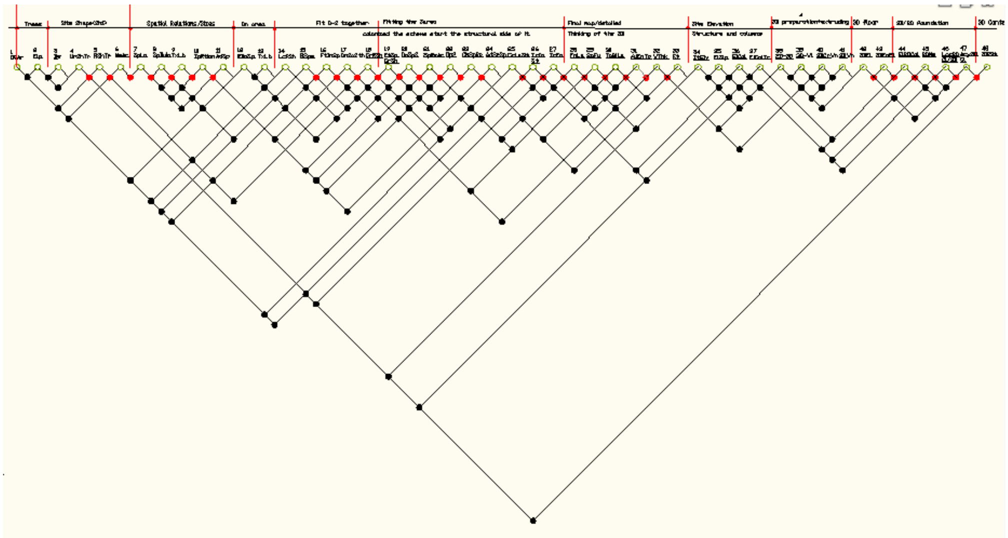


Figure 9-32 ST3 design process linkograph.

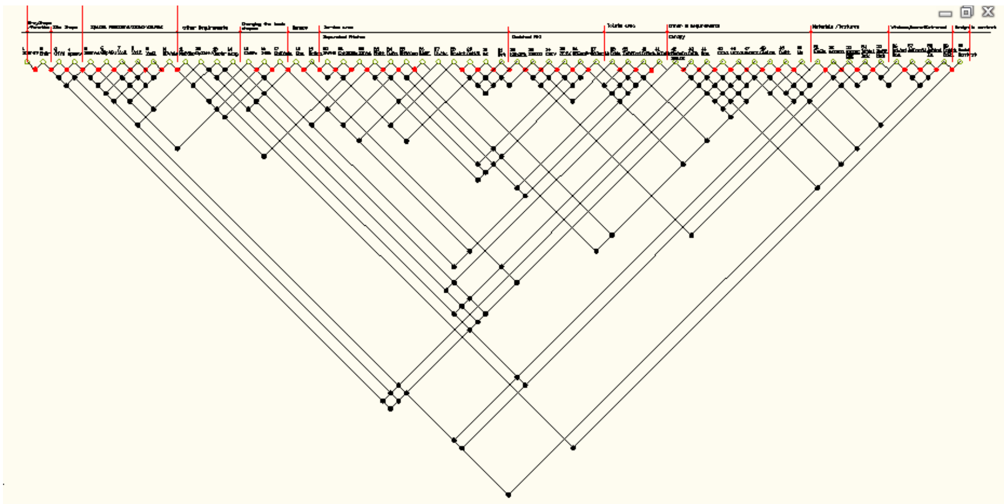


Figure 9-33 ST4 design process linkograph

In design reasoning, structure and content correlates (Goldschmidt and Weil 1998). Accordingly, a productive move in a Linkograph spreads in two directions, therefore, identifying the critical moves (CMs) in terms of its conceptual connectivity describes design process advancement. These are presented in the following subsections.

9.6.2 Linkographic coding analysis

The design protocols are described quantitatively through linkographic measures of link indices (averages), critical moves and percentages. An average of fifty-three moves was decided by the students that created an average of 160 links among themselves in an average duration of 59 minutes. As shown in Table 9.8, the Link index for SA1, SA2, ST3 and ST4 are 3.1, 3.2, 2.8 and 3.1, respectively.

Table 9-8 Linkographic description for all cases.

Cases	Duration (hr:min:sec)	No. of moves	No. of Links	Link index	%CM5	%CM6	%CM7	%CM8
SA1	00:57:28	46	141	3.1	13	**9**	4	**7**
SA2	00:45:18	60	190	**3.2**	**19**	7	**7**	**5**
ST3	01:19:41	48	136	2.8	**19**	**10**	2	2
ST4	00:56:55	60	186	3.1	10	5	3	3
Av	00:59:00	53	155.5	2.9	**15.3**	8	4	4

SA2 (multi CAAD programs) had the highest LI among other protocols. LI value was the same for SA1 (single CAAD program protocol) and ST4 (single CAAD program protocol), while ST3 protocol had the smallest value. This means that SA2 multi CAAD protocol is the most productive. This may suggest that switching between two programs may be better in terms of the content and the structure of a CAAD design process as he also solved the problem in 2D then 3D.

With respect to critical moves (CM) and percentages, CM is a move which has at least 3 links in one direction to 8 links. The threshold varies upon the research purpose and cases (Goldschmidt 2009 personal communication by email), therefore this was decided through the percentages of (CM^5, CM^6, CM^7 and CM^8), as shown in Figure 9-34.

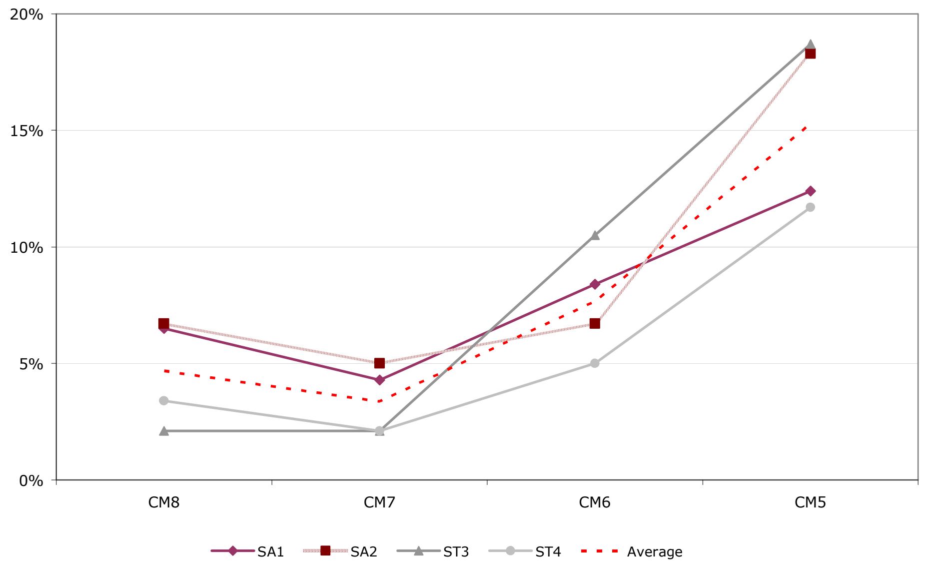


Figure 9-34 The critical move by link level and their percentages of the total moves and the average percentage for all cases.

The percentages of critical moves of five links, (either forward or backward CM5), was the highest percentage which ranged from 10% to 19%. Likewise, CM5 percentage was the highest among other CMi for each participant.

9.6.3 Link density in clusters

To examine the conceptual continuity in terms of the association of design ideas to reflect on the study question: What association can the ideas that were expressed during the protocol have? Cluster density was computed. A cluster in the design process (constructed linkograph) means a successive number of design moves, more than three (Bilda and Gero 2008) that are linked and have a serial conceptual dependency. This reflects on the “suggestive” design moves of a design process, which is followed by a series of moves that explore issue (s) raised by the suggestive move (Goldschmidt 1995, 2003; Goldschmidt and Weill 1998; Dorst and Dijkhuis 1995) or the other related moves within that cluster (Bilda and Gero 2008). In other words, this means that the clusters refer to the evolution of a partial idea towards a tentative design. The number of design moves that form a cluster, define a cluster size. For example, if five consecutive links were in sequence then the cluster size is six, because six design moves formed five links cluster. These links spread to relate to other design moves along the process in both directions: forward and backwards. To know what type the cluster is, the links are counted in both directions to define whether the cluster is a forward or a backward one. According to Bilda and Gero (2008) this helps to know the density of a cluster by dividing the total number of links of a cluster on the size of a cluster.

Table 9-9 Clusters and density of links.

Student	No of clusters			Average size of clusters		Link density in cluster	
	Forward	Backward	Total	forward	Backward	Fore-links	Back-links
SA1	2	4	6	9.5	6	6.3	5.4
SA2	2	4	6	8.5	6.8	11.5	7.4
ST3	2	4	6	6	7.5	6	3.9
ST4	3	4	7	11	5.8	4.7	6.7
Av	2.3	4	6.3	8.8	6.5	7.1	5.9

The results of the total number of forward and backward link clusters, size of clusters, and link density in the clusters for all participants are shown in Table 9-9. Six clusters were identified in three of the linkographs of SA1, SA2 and ST3, and seven clusters in ST4 linkograph. The number of backward clusters in all the linkographs was higher than the forward clusters.

This suggests that CAAD affected the students in two ways: (1) made the students revise, evaluate and repeat their ideas more often than generate or propose, and (2) to an extent made the students less inventive in terms of the number of new ideas, however, the nature of the task and the time required to finish the experiment should be considered. These points agree with Goldschmidt's definition of the backward and the forward critical moves (1995 p.205-6). Another point to discuss is the observed positions of the two types of cluster. In each of the linkographs the first identified cluster was a forward cluster and the last two or three clusters were backward clusters. This suggests that most of the participants from the start of designing started to externalise their ideas, whether through CAAD or words to reach a tentative solution to the design problem. Also, it suggests that the initial ideas are deemed to be the most successful moves that a designer makes which enable the designers to further develop their earlier ideas. (This confirms the results of the transition from one conceptual segment to another conceptual segment, which is presented in section 9. 3.4).

In between the first and the end clusters there was no common pattern for all participants, but rather interplay between the two types. Two of the participants (SA2 and ST4) showed continuous behaviour in constructing forward ideas, the other two, SA1 and ST3, inverted their ideas backwards to what they did in the first cluster to improve and check for two successive clusters (no 2, 3). Then engaged in forward thinking (cluster 4), ST4 showed a different pattern of continuous forward thinking and then spent the later 4 clusters in reverse thinking. This is shown in Figure 9-35.

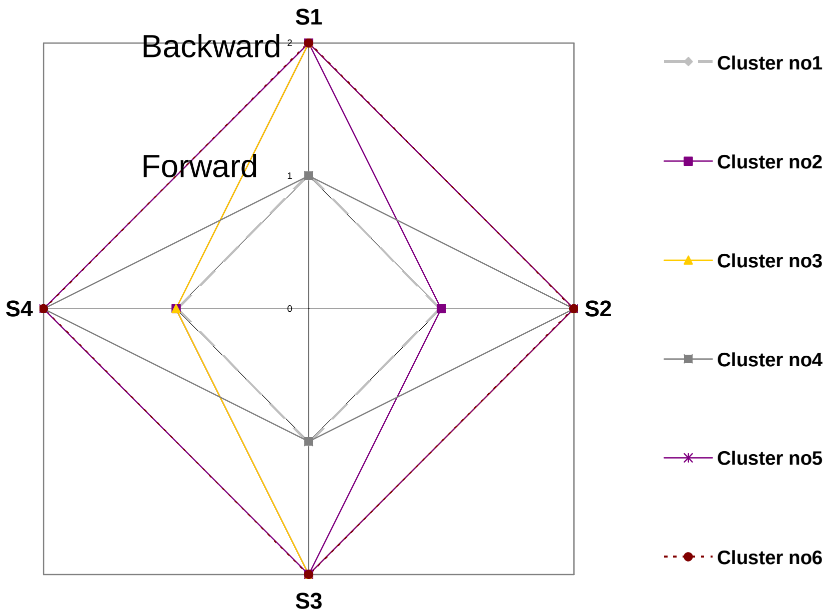


Figure 9-35 the types of the clusters in the same sequence of occurrence.

Coding the clusters with colours showed the crossover of clusters in the linkograph, mainly in the shape of triangles. This suggests that every cluster spreads in both directions to form a joint smaller pyramid and as a result, all clusters were interconnected. When the student is satisfied with the result he mostly inverts his thought backward to relate to earlier thoughts.

The average size of clusters was higher for the forward clusters compared to the backward clusters. It was also higher for all participants in the forward clusters except ST3. It also shows that the fore-link density is relatively higher than back-link density; as it was higher for all participants except for ST4. When the fore-link density is higher than the back-link density it means that the forward clusters initiated more ideas later on in the process (Bilda and Gero 2008). High density reflects rich idea development and that these ideas were potentially successful.

The number of coded moves was relatively lower compared to the initial number of segments. The difference implied that the segment includes a larger amount of information than a design move. This is due to the fact that when a segment is coded under the design micro strategy, the intention is one, for example proposing a solution, or evaluating a solution, where as this intention could include more than one idea or more than one design move (act that changes the design situation). For example, proposing a design solution could include one or two different ideas or developed ideas, especially when the segment was externalised verbally. Normally the student becomes more concise when externalising graphically, thus, the number of segments in the design process-coding scheme was higher than the number of design moves in the linkography-coding scheme.

Another observed feature is the qualitative meaning and extensiveness of the words used in the verbal subpart of the protocol. On the general level of design protocol and on the specific level of ideas connectedness, two aspects were observed. On the general level of protocols' transcriptions, words such as 'maybe', 'probably' , 'possibly' and so on were used which reflect the ill defined nature of the design situation. On the specific level of ideas connectedness, another aspect of design moves' connectedness was revealed through tracing the common words (discussed in section 5.6.1.e, according to Bilda 2006) between segments to see whether two distant moves were connected or not. This process revealed an interesting character within three of the analysed protocols (SA1, SA2 and ST4). That is, some of the words used had become more extensive; the words (which have conceptual traces) that were verbalised during designing were changed into more inclusive and specific meaning along the timeline. This change is due to the change in the design status and design conceptual maturity, due to the evolving context of the design process. This was also traceable on the level of density clusters which appeared to confirm the conceptual progress, but mainly in forward moves and forward clusters.

9.7 Participant's Comments and Discussion

The results of the two analytical methods suggested that students were comfortable while using CAAD for designing and felt that the result was ample for presentation. Participants' reflection on the experimental situation and the associated conceptual design suggested similar themes to the previous studies, however, the investigation was on the micro level of an individual design activity.

9.7.1 CAAD as part of the design situation

The students participating agreed that if they used sketching for ideas' externalisation then the designs would be similar to the ones they produced with CAAD external representations. Three of the students (SA1, SA2 and ST3) reported that their ideas would be similar if they were to use either CAAD or sketching. Quoting SA1: *"I think in ways could be similar I think everything, every different part of where you are when you are designing can affect your design. The initial moves I made I would have made in a pencil as well addressing the house, and addressing the school and addressing the trees and forming the shape, and other aspects that I got I don't think I would have done that differently with a pencil."* (SA1). Student SA2 also agreed "*Those things (design elements) may be stayed the same but the way I did them slightly different...I probably would not go through the same process if you give me a pen and a piece of* paper." At this point he acknowledged CAAD's positive effect on the conceptual design process recalling the visual effect of subtracting the two volumetric shapes (pavilions and the roof) that SketchUp Boolean operation had on the conceptual design. Quoting SA2:

> *"But then just this sort it works of the software the way it does things the design develop in a different way to how I thought it might be."*
> *"Because of the software it did something and made me think oh actually do it in a different way and this kind of pocking up from the roof it comes from."* (SA2).

To some extent ST4 suggested a similar acknowledgement, however, the means were different. Quoting ST4:

> *"Well I think it is greatly affected this roof shape, if I was not using CAAD I would not probably come up with the shape of the roof, and the shape of the canopies as well I would not probably adventure towards that."* (ST4).

In the case of SA2, the gained visual insight stimulated his thinking and made him retract what he had decided previously, whereas ST4 created the roof shape according to his vision, not as a result of the software mechanism.

Most of the students participating (SA1, SA2 and ST3) indicated that they would normally start a problem-solving activity with sketching to get their ideas down on paper first, before moving to CAAD. Even if they were given a CAAD drawing (for example site, layout or existing building) they would print it off and get the initial idea down by hand, then move back to CAAD. One student, ST4, (a 4th year architectural technology student) indicated that he would normally start with CAAD (skilful in AutoCAD, SketchUp and ArchiCAD). He said: "*I don't really tend to sketch on paper I tend to do it on the computer and find out forms. I find that a lot easier than sketching on paper."* One reason for this tendency is the student's interest in formation, as 3D manipulation is facilitated in CAAD rather than sketching. This student provided the study with a unique example of a student approaching design through 3D forms.

The four students described their interaction with CAAD's representations as co-operative in many ways. To summarise the ways in which CAAD was helpful or aiding the thinking process, the following aspects were revealed.

In the case of SA2, the student experienced unexpected visual formation that was CAAD based, which resulted from SketchUp volumetric subtraction while drawing an attached shape to a previously drawn volumetric shape. The acquired visual feedback affected the student's conceptual intention. Quoting SA2: "*When I pulled the (drawn shape of the roof). When SketchUp did the roof and left the gaps".*

An important point was noted when this automated effect made the student hesitant to claim responsibility for this act and result : "*I pulled.."* into "*SketchUp did...",* not admitting it as a self action but admitting the software way of doing things. Moreover, the immediacy of CAAD's visual feedback led the student to change or alter his thought and further build on it conceptually. Quoting SA2: *"So when I saw that I thought oh! The design probably changed slightly from what I was originally thinking because of what SketchUp was doing and just the way SketchUp was doing things*." A similar quote was: "*I suppose I must have noticed* *that I never thought about it before it is not actually me, is just the way the software is done something that changed it."*

In brief, this reflects computer-aided design in two contradictory ways, (1) the resistance to automated consequences, effects, results or interaction, and (2) the acknowledgement of CAAD's potential impact on visual thinking.

Most of the students indicated that they had visualised the proposed ideas in their heads before CAAD (interacted with the mental imagery or mental construct first), and these mental constructs were referred to in 3D mode, for example 3D building. In fact, students described such constructs partially, quoting SA1 "*I could not see the whole thing in 3D in my mind."* Further explaining what he did see mentally: *"It was almost building from the ground up and I was thinking about how the structure would come down and meet the ground and that was all what in my mind*." (SA1). A similar meaning was mentioned by SA2 *"I would say similar but definitely not the same."* to emphasise the similarities between the mental constructs and what he had done through CAAD representations, at the same time, acknowledging the visual feedback that was gained from CAAD's operation.

ST4's preference for CAAD was based on two points: 1- CAAD 3D representations are aiding the students to "*being able to visualize objects in my head as well.*" This was one of the reasons for this student to use CAAD solely for externalisation, besides skills level, and motivation to use technology and practical experience. This design protocol provides an example of how the level of interactivity may change from an external interactivity with 2D visual representations, to an internal interactivity along 3D manipulation.

Another feature of students' design behaviour was on the level of their internal representations. Students mentioned that they were able to see a similar 3D representation in their minds before starting to design and after reading the brief or visiting the site but it was not finished yet. Interacting with CAAD representations helped them to recognise the rest of the design and to recognise the final state of this 3D construct.

Some of the mentioned factors may facilitate students' interaction with CAAD external representations by decreasing CAAD's characteristic impact, for example accuracy of the design tool. One instance was student's familiarity with the design situation or part of the design situation which may facilitate an easier design process. One of the participants stated: *"I think it helps that I know the site if I just gone on CAAD, and [don't know] the site at all then it is not restriction but it is not the freedom but since I knew the site I didn't feel restricted really.*" (SA1). Another factor was associated with CAAD immersion: "*I think it was quite simple and time flies when using AutoCAD, it really does, when you are busy and thinking as well it seems quarter an hour rather than an hour*." Being immersed in CAAD while designing facilitates the continuity of the process.

Participants' comments revealed that CAAD improved the following design activities:
1-using CAAD did not change participants' initial ideas (internal), but external representations were helpful to envision these constructs fully.

2-using CAAD helped participants reach 3D constructs or details which would not otherwise have been reached in paper based media.

3- using CAAD helped them see instantly the appearance of the designed construct or idea. Quoting one participant: *"Very much the appearance I think it is so easy to add the textures on and immediately you get a feel of the building whereas may be on paper I would may be go to the contextual approach, but certainly here I would because it is so easy to get a quick idea of the form and how aesthetically is going to look as well."* (ST4).

4-using CAAD helped participants' to externalise their pre physical constructs and interact with CAAD external representations to complete the previously held mental constructs, quoting one participant: "*I did not see the roof yet in my mind, so it was not an entire building in my mind, my drawings lead on to that."* (SA1).

5-Using CAAD helped one participant who is " *not particularly good at conceptual design in my head*" but interacting with CAAD representations on a deeper level of interaction helped to change that.

Participants' comments revealed that CAAD influenced the following design activities:

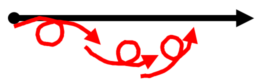
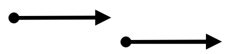
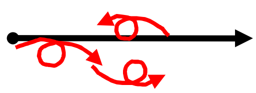
1- using a different CAAD program may change the way and mode of starting the design process, that is 2D or 3D. Quoting one participant: *“if I was using AutoCAD as oppose to SketchUp I would start in to plan and visualise the layout, I suppose I did it similarly here visualised the layout if each building and then project it up an created the form in the same way that I would do it in CAD but I will need to have an idea of the face.”* (ST4).

2- using CAAD may bring previously created constructs as part of student’s learning effect within a computerised environment. Quoting ST4: *“Whereas this is so similar to designs I have done before. I have influenced that upon designs I may have done in the past so I don't feel that I learned a lot. do something that I were not familiar with.”*

3-using CAAD influenced participants’ thinking in how to strike a balance between the complexity of the two parallel tasks: of drawing in CAAD and thinking of the drawn object with respect to design. Quoting one student: “*I think it is a mixture of both I think because sometimes an easy operation becomes more complicated in CAAD.”(*(SA2). Another student (ST4) said : “*I do find it easy but I think sometimes it can take over from your thought sequence as well. I am possibly thinking of one part of the model and suddenly get side tracked because I am tried to draw something that I have possibly forgotten something that I was possibly thinking about “.* and *“So I think it may does alter how you think about drawing something as well because you then are manipulated by the way the package draw it as oppose to how it might be drawn by hand.”*

In light of the students’ comments and as a result of design-oriented coding schemes (design micro strategies, level of abstraction, CAAD representations) and design moves and links coding, many patterns were observed and defined for each participant as shown in table 9-10.

Table 9-10 CAAD impact on the design process has been classified into practical and technical.

Patterns / strategies	Instances	Reason	Design Process Pattern
Interruption e.g. Failing to zoom (3D/SketchUp) that would happen unintentionally	Found in SA2 and ST4	Technical	
Shifting/deviation Engaging in non conceptual design activity, e.g. assigning material, completing missing surfaces in 3D	Found in SA2 and ST4	Practical	
Trial and Error Learning "how to" while designing. (This means that learning CAAD as a design tool should be contextualised in design problem solving).	Found in SA1 and SA2, ST4	Practical	
Platform change/CAAD switch Compatibility issues, scale and defining objects	Found in SA2	Technical	
Pausing: Taking a break as a result of mental tiredness by doing menial task i.e. adding text.	Found in SA1 protocol, but was observed in other protocols (ST3 and ST4)	Mental/ cognitive	
Focus on superficial properties of the conceptual design.	Found in ST4	Mental/ cognitive	

9.7.2 Experimental setting

ST4's design behaviour was quite different from the other participating students and the general finding of the case study. Because ST4 felt comfortable with the design situation and reflected on it by saying: "*where as this is so similar to designs I have done before."* While the other students (SA1, SA2) felt positive about the experimental condition and commented that it was "*an easy*" challenge, ST3 said it "*felt weird at the very start"* of the session because he was *"not used to use CAAD for conceptual design.".*

In the case of SA2, this student was the only participant who had been recruited in the first study, volunteered in the studio reflection study, and participated in the protocol study among other participants. Given this background, he acknowledged the design protocol experimental method "*as a good way to wrap it up*,". By "it" the student refers to the main theme of this thesis: "CAAD use in conceptual design/ early phases of design" which is the investigative theme of this thesis. This method gave him the opportunity to experience how CAAD might provide positive medium for visual design exploration. Quoting SA2: *"I have answered all of the questionnaires and been to the focus group but it is only until today that I have realized a lot of the things you have been saying, that I have been doing I have [never] been aware of."* Having only used CAAD for externalisation and already exposed to this kind of interaction, the student developed an awareness of how CAAD might aid designing or visual interaction.

9.8 Summary

The protocol studies sought to characterise students' design interaction (design activity) while designing with CAAD programs and characterised CAAD's 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.

In light of the study results, the participants demonstrated that, for the same design problem (brief), restraining the conceptual design medium would not necessarily bind the participants to a certain design strategy or hamper the arrival at a tentative design regardless of its academic assessment. Instead, the conceptual structure and linkability of ideas was assessed using the linkography method.

This study is an attempt to characterise students' design thinking while designing with CAAD programs. The analysis represents four design protocols of final year students (fifth year master of architecture and fourth year of architectural technology) at a school of architecture. The analysed protocols varied in more than one aspect. This variation includes: (1) CAAD programs, (2) the mode of using CAAD programs whether single or multiple, (3) protocol segments (total number, duration and frequencies), and (4) design categories and total time spent in designing. This gave an updated insight into design thinking (process) while using CAAD programs in architectural design with final year students.

A CAAD design protocol, whether it is a single or multiple CAAD, was characterised by a low number of segments with higher durations suggesting that participants designing with CAAD will have relatively longer shifts of intention compared to sketching protocols. Another feature was the frequency of intention shifts which varied within the same protocol and among the participants, so there is no distinct mode. One design protocol showed a different behaviour in terms of these measures, which was a CAAD multi design protocol. Using more than one CAAD program that is different in their characteristics broke down the lengthy segments. In general the early intervals of CAAD design protocols witnessed higher transition rate than the latter intervals.

CAAD representations were used for three main purposes: conceptual, informative, and presentation. Two dimensional representations were mainly used, apart from one participant, and were the basis for three dimensional drawings. Overall, 3D was based on 2D to reflect the traditional strategies in design learning. The relationship among the created representations was linear for the most part of the process, and rarely cyclic. However, this varied according to the CAAD program used: AutoCAD or SketchUp. The students who used AutoCAD engaged in 2D diagrams and used similar problem-solving strategies to imitate the method they taught. The students who used SketchUp engaged in 3D modelling, whether conceptual or presentational. The only student who used 3D for problem solving showed a different problem solving strategy because he did not solve the spatial/ functional requirements before moving to 3D. This was not similar to the traditional way of designing.

The analyses of ‘design micro strategies’ coding highlighted individual differences among participants. This showed that participants spent relatively low percentages of time on analysing the design problem and most of the design process time was spent on proposing a solution but predominantly through clarifying a solution by adding more details rather than repeating a solution or modifying a solution. Participants spent less time on analysing the design proposal as perhaps they were not motivated to do so.

Moreover, participants were able to navigate through the different levels of abstraction without visual restrictions. On average all participants spent most of the design process considering the design at the levels of site layout, layout zoning and layout detailed spatial relations. However, some of the participants spent a considerable amount of time on level 4 (CAAD based level of detail) considering the drawing on a detailed level. At first glance, this may suggest that a shift occurred form level 0 or 1 to level 4, but when considering the low percentage of analysing the problem, it seems implausible to assume that. CAAD may deviate participants’ level of abstraction but not at the expense of the other levels.

External representation occurrences suggested that participants were engaged in proposing a design solution mostly through create and modify representations acts. Participants’ problem solving approach affected the acts used, depending on whether the participant was using a graphical analysis or not, for example bubble diagramming or zoning.

Mapping between the occurrences of external representation acts and design micro strategies suggest that participants were engaged in externalising and reflecting on CAAD representations while using other types of external representations with lower levels of uncertainty, for example proposing ideas verbally, which might be one way to manage CAAD’s difficulties while designing.

Furthermore, the design process continuity was analysed through constructing design process linkographs. What characterised the continuity of CAAD design protocols is the number of ideas in association with design moves along the timeline of the design process. The protocols were characterised by high linkographic measurements: Li, CM and Ld. However, the participant who used more than two software programs showed higher Li from the other linkographs. This characteristic alongside other results suggests that using more than one CAAD program may increase the connectedness of conceptual ideas along the design time line, and a higher number of forward clusters .

Participants comments were positive about the design situation and the experiment. However, the ones who used CAAD early in design were regularly more positive about using CAAD in concept design.

On the basis of these results, interacting with CAAD visual representations can be accepted as a conceptual medium and the use of CAAD alone for externalisation. However, the study suggested that this may vary upon:

- students' learning background and whether traditional design methods are dominant.
- students' design method and whether students have a certain design interest, for example form generation as a starting point for conceptual design.
- students' motive to use technology and CAAD.
- the used CAAD programs and their characteristics.

Moreover, the protocol study objectives were met successfully by providing CAAD oriented research and design research with deeper insights into students' problem solving processes and methods. The potential impact of CAAD on the micro level of design activity was identified and categorised.

10 Discussion and Conclusions

This chapter presents the discussion of the results and findings of the main studies with respect to the research objectives. The findings are discussed individually over the first two sections: the case study (survey, reflection study and focus group) in the first section, the design protocol study in the second section. The implications of investigating CAAD programs are discussed in the third section through a triangulation of findings. The limitations of this research and future work are presented in the fourth section, and finally the chapter presents the research conclusions and recommendations.

10.1 Case Study

The survey was employed to improve our understanding of how final year students perceive CAAD in the later years of their education, and identify how CAAD teaching methods have influenced their views. Students' general attitude toward computers is found to be highly positive; hence they are motivated to use technology. In recent years, many surveys have been carried out on junior students which showed that they are highly motivated to use CAAD reflecting a positive attitude about technology. This result agrees with previous CAAD-oriented studies, Pektas and Erkip (2006) and Penttilä (2003) and Hanna and Barber (2001) which explored design students' attitude toward computers in general and CAAD in particular to suggest that using CAAD became a "socio-cultural" issue in the first place and a " technical issue" (Pektas and Erkip 2006) in the second place.

The study sample of final year students shows a similar attitude to CAAD. With respect to van Dijk's (2005) staged access to digital technology, the students at this stage have passed the motivational access and material access (high possession of laptops, CAAD and Internet) hence gained the required digital skills (third stage of access) to operate a computer. The first two accesses gave the opportunity to explore CAAD in relation to their design development. Also, discretionary access gave the student a crucial source of learning (van Dijk, 2005), and this could be related to learning by doing or by trial and error. One indication for this, *personal effort* was reported as the main source for their CAAD learning and skills. That is to say, final year students (and younger years) need an emphasis on CAAD usage through project-based learning strategies.

With respect to students' early start and their exposure to slower or less advanced CAAD systems and teaching methods, their CAAD skill self-assessment was above the average level (mean score of 3.68) in basic 2D and 3D modelling. Thus, they did not show any bias in terms of CAAD skill as they were extremely consistent in assessing their design and sketching skills and inconsistent in assessing their CAAD skill (range is higher than other skills) to suggest two things: CAAD skill level varies within the same sample or stage, and subjectively assessed as there is no module to frame it especially when it is self-taught.

The second highly ranked source for the sample's CAAD experience was "architectural practice". University courses came third to suggest that students appreciated the context that was provided by the architectural practice in terms of design-based practice, positive attitude, observing other (new) design methods and possibilities. This implies that they have learned more from such a setting compared with the way CAAD was taught in schools of architecture. Where CAAD is taught and used in a separate setting from the design context (QaQish and Hanna 1997) and isolated by the tutors' perception of CAAD.

The majority use CAAD regularly in both phases of the design (early and final) and a minority use CAAD in the early phases. CAAD is defined primarily as a drafting tool or a tool for drafting and designing but rarely as a designing tool. Moreover, students' use of CAAD has affected their design capability but has not improved their architectural design skill. This implies that the students' usage access is also high (van Dijk 2005) though this is not clear in terms of the applications, the time spent using the applications or what they have been used for. This supports Pektas and Erkip's (2006) findings of design students' attitude to computer use in design. They identified that design students have positive attitudes to using CAAD but it was not the same when students were asked about using it for producing conceptual design. However, on the level of conceptual design, more than half of the students reported that they used CAAD for *generating* conceptual design to a certain degree, stating that CAAD is aiding concept design which, in turn, suggests that the relationship between CAAD and concept design is moving forward.

The survey reported AutoCAD as the dominant professional system used by all (100%) of the sample at this stage. Penttilä's (2003) survey previously stated that

AutoCAD is the market leader in European schools of architecture (80-90 %), followed by ArchiCAD (Penttilä 2003 p.604). However, this may change with the development of technology in general and CAAD systems, in particular. Therefore, CAAD's software market and the preference of architectural practice (professional) will always affect students (Garcia et al., 2007) and influence academic choices. SketchUp was reported by 64% of the sample as the second favoured CAAD program. In recent years, SketchUp has become popular in academia, practice, and in digital design studies. The combination of these two systems is useful for design exploration (Dokonal and Knight 2006; Zuo, Leonard and MaloneBeach 2010), because of the differences in the nature of the two software programs. Having skills in both software programs, helps the students to be critical regarding which program is best for specific design tasks and which offers flexibility rather than restraint. AutoCAD is described as difficult requiring more time to learn and practice (Al-Qawasmi 2005) and SketchUp is described as friendly, easy to learn and "less forgiving" when compared to 3D physical modelling (Zuo, Leonard and MaloneBeach 2010).

This combination of CAAD programs implies that students are being exposed to different design methods which should be compliant with these types of CAAD programs; this may be on the level of how to start designing, and 2D or 3D mode. On the other hand, there is a similar tendency to combine digital and traditional representations that reflect the deficiency in either CAAD skills or traditional skills (Lawson 1999; Zuo, Leonard and MaloneBeach 2010). The reiteration between the two media has positive consequences on students' visual thinking as the different characteristics bridge and brings new insights. The results showed that students normally start with sketching before moving to CAAD and tend to switch from CAAD to sketch in a process of conceptual development and refinement. However, the combination of the two representations influenced students' tendency to sketch less, compared to when sketching only is used. This implies that CAAD accuracy is replacing some of the techniques used before to check idea feasibility, such as Grid Paper. This supports other studies (Al-Qawasmi 2005, 2004) that have looked at the dismissed traditional practices.

Two aspects of the CAAD representation used were reported: (1) working on the appearance, details and finishes rather than the actual content of the concept, and (2) balancing between what they are drawing and how to draw it, which were elaborated in more detail in the protocol study.

Describing the sample in terms of 3D representations, the students agreed that exploring their design early in 3D (using either media) is useful for the following: concept design development, concept design variation and new insights. They also reported that creating 3D models affects their work on the following: imagining spaces, representation, perspective, and form visualisation.

Students sometimes tend to create digital models at any phase of concept design development, but they would rather create a digital model for the final sketch design and outline design because it is preferable to traditional models for its speed of completion. This implies that 3D CAAD is used later in the design process when time is short and insufficient to explore other conceptual designs.

Bearing in mind that students spent the last year in placement, they were exposed to CAAD professional practices. Therefore, final year students favoured the architectural practice as the most useful way to learn CAAD as a *designing tool*. Moreover, they identified the lack of a systematic way of using CAAD in design methodology. As a result, this study suggests that CAAD systems must be taught in a situated manner to go further than the external interaction with the representations.

A semi-structured reflection study was employed to address the following objective: to improve our understanding of the role of CAAD software programs in the traditional design studio of final year students. The study reflected on the *process* of interaction between students (sample), their workspace (tools; CAAD, drawing, modelling, etc.) and the project model which would help students in developing their ability using a case study approach. Utilising CAAD in the traditional context of the studio and the educational framework had been recognised (in chapter 3) as a complex social phenomenon. The purpose of this study was to collect data on the same variables (skills, views and design media practices: sketching, CAAD and modelling) within the proposed boundary of space (studio) and time (project program).

The studio dynamics of learning is housed in the project-based approach of the architectural school alongside the identified characteristics of final-year students; these have framed students' (generated) reflection in that context. The interaction between a student and a tool is arguably spontaneous in the studio context. Such a situation of spontaneous interaction between students and tools provides the conditions for students' critical ability to develop (Meneely and Danko 2007) within the context of a design project. In general, this study showed that such interaction is controlled by the project model and the stage pedagogy. However, different degrees of control were observed based on studio work progress. Therefore, developing students' critical ability to evaluate the usefulness of a tool depends, for the most part, on studio work and the degree of control.

The first theme discussed is the studio model. The project model integrates CAAD passively (as a 2D drafting tool), and limits CAAD's usage to changes, modifications and production, with a narrow focus on experimenting with design concepts and discovery (Coyne, Park and Wiszniewski 2002). Moreover, the focus on using conventional means of exploration may hinder CAAD utility hence learning to used it during conceptual phase of designing.

Analysis showed that there was no schema for CAAD integration, apart from a warm-up project whereby the students were asked to "…*record and represent the essential tonal, figure and line qualities of an architectural place with a 2D CAAD drawing*." The main outcome was to assess the student's "*ability to construct a cohesive and comprehensive study/survey of the study types covering all the required areas*." (Warm Up-Project-JW-2006). This introductory project is a typical task for CAAD but it implicitly outlines the intended role for CAAD use within the project model. CAAD is used for drafting, documenting, and presentation, and to some extent to evaluate the individual skills of CAAD usage. This was described by one student (Sa 4) as "*there is no challenge in CAAD"* drawings.

At such an advanced stage of architectural education, the graduates must be prepared to step into industry with a good degree of confidence in their abilities and skills. Architectural education and educators should be concerned if CAAD was not integrated within the project model, arguably, systematic integration of CAAD would provide a rational guidance and enhancement in terms of design methodologies and contemporary design abilities. This would provide the context (design problem, situation and design phase) for the interaction to occur between the chosen tool, student and the student's critical ability to judge the tool's utility. Reffat (2007 and 2007a) emphasised the importance of a good pedagogy that informs and supports IT, which otherwise would affect student's learning and architecture. Integration is also important for gaining the ability to be critical about the design tool used which was suggested by Meneely and Danko (2007) and claimed as a "*responsibility of understanding*" by Reffat (2007).

Regardless of what learning outcomes are anticipated in phase one, the students explored many conceptual issues through various design media. The methodologies that were utilised by the students were mainly drawing and physical modelling.

In comparing the responses at the end of the project with the former questionnaire survey at the start of the semester, it can be noted that there was no significant change in their responses with regard to how they used CAAD and why they used it in the process. The amount of design work that was done within the project model, regardless of the types of design knowledge the model prompted, was not successful in modifying students' perceptions of CAAD, or widening their practices with regard to architectural practice of real design processes. CAAD *evolutionary* learning has continued to be contextualised passively in the presentation subpart of designing. There were, therefore, three missing criteria for CAAD *evolutionary* learning:

- The students' responses reported no significant learning apart from some representational techniques.
- There was no further preparation for final year students for CAAD as part of their professional life, and
- The early use of CAAD is mostly influenced by tutors' negative attitude toward CAAD.

Design media had a pedagogical agenda at the studio which is explained through the findings (observations). Each phase was characterised by the chosen media. The early phase focus was on constructing physical models therefore students did not need to create 3D digital models. Consequently, students missed a contextual opportunity to acquire 3D CAAD skill which was often reported by the group as lacking. Thus, in this phase, to an extent, media is controlled by the project model requisite and students' perspective on what varied from *useful* to *waste of time*.

The second phase characteristics were smaller CAAD representations; changing the size of CAAD representation was helpful in changing the presentational status of it into an analytical status. Dogan and Nersessian (2010) contend that designers develop strategies that facilitate the process of *abstraction* and *exploration*. Small CAAD representations would maintain the designer's foveal vision (Lawson 2004) and change students' perception of CAAD representations (drawings) from detailed and finished into analytical, personal and enjoyable. This would affect students' use of CAAD (small) drawings for concept design.

The nature of interaction between the student, tools and project model within the studio context may change through representational changes which could affect the use of CAAD drawings in concept design (for example in the case of Sb2) to act as an intervention between CAAD representations and sketching by printing out small sized layouts or diagrams. This brings changes to how CAAD representation is perceived and how this interaction becomes self-controlled. Students often start from drawing in 2D CAAD mode as they need it at different points in the process, therefore learning may proceed from 2D to 3D skills.

The students agreed that the tutors' attitude towards CAAD use (AutoCAD in particular), influenced students' attitudes and practices. This is in agreement with Pektas and Erkip's (2006) study of tutors' attitude towards CAAD versus students' attitude. There is a conflict between the two that led to reluctance to include CAAD within the teaching of design. Bassa and Senyapılı (2005) suggest possible reasons for this reluctance are tutors' habitual skills and no CAAD professional development. In addition, perceiving CAAD as a drafting tool (see Hanna and Barber 2001) in academia was another factor in keeping CAAD away from concept design. This study showed that learning CAAD is influenced by two effects. The first effect brought in the tutor's perspective of computer aided drafting (as opposed to designing) and the second effect brought in the student's critical appraisal of needing CAAD for a certain design situation.

The split status of students' conceptual design was observed, as the students were engaged in the precedent study. Lawson (2004a p.10) said that recognising schemata, that is underlying structure of a precedent, is a key skill: "*Seeing some kind of underlying pattern or theme that enables a designer to recognise this and make a connection with some precedent in the episodic memory*."

Although the majority of the students consider and perceive CAAD software programs as a drafting tool (section 6.2.3 of the survey study), it affected their conceptual cycle sequences and consequences. Studio reflection provided an example of this. The student used CAAD as a drafting tool in an analogical study of the existing building; the student was able to reach a design proposal, based on the findings of the systematic investigation of the existing building form. These studies also enabled students to move forward and make further decisions, as these CAAD drawings assisted student understanding of what the concepts of the work were and the significance of it. Moving to CAAD 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 another variation.

How to elevate students' design skill is an important issue. As mentioned previously, section 5.1.4, the choice of sample of final year students was to reduce the differences in design cognitive abilities and to have cohesive understanding of the skill level and its impact on the used media. Using CAAD with no experience seems to reduce the possibilities for designing (Coyne, Park and Wiszniewski 2002; Jonson 2005). For example, one particular participant doesn't have efficient 3D skills to practice 3D CAAD modelling but by using conventional ways of isometric drawing, he was able to achieve a 3D view of his form analysis. This case (Sb2) study confirms Schenk (2005) findings in terms of how to integrate CAAD into the drawing curriculum, not the opposite. On the other hand, this gives another example of how students have a tendency to apply conventional design skills to any other visual media; referring to the potential adaptation (Breen 2004; Schenk 2005).

The combination of physical and digital media and design methods adds 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 leads to creativity.

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 modes (Breen 2004). Although digital media has become an option, this does not mean that integrating digital media should develop into a discrete process, which excludes all other media such as sketches, photographs and physical models, simply because each addresses different sensibilities that better capture other aspects of design.

Along the emergent themes, time was mentioned: "*To take a while", "To some extent", and "time schedules" as* an influencing factor in using CAAD. It is a factor in two senses: time needed by the student, and time needed for the task, which would affect student's ideas and sense of fulfilment. This shows students' awareness of such constraints before reaching what they want to achieve therefore, time is one of the factors that bring CAAD direct and indirect practices to the studio as the general perception relates to CAAD being favoured for its quickness. Moreover, the study showed that students are willing to use CAAD at any point of the project where there is a need for accuracy, neatness and speed, which normally occurs after reaching a satisfactory status of the design concept.

Many studies on studio context emphasised the dynamic nature and the sample referred to it as a medium for interaction. The architectural design studio is the context for student interaction to occur and learning in action, as students credited their friends and reviews as the most influential factors on one's learning and CAAD. The most influential context is the studio in terms of CAAD learning and conceptual engagement. This agrees with the findings of Chiu (2010).

The earlier findings were further probed and corroborated in a focus group discussion after the completion of the two semesters' projects. The participating students were keen to separate the term CAAD into AutoCAD and SketchUp, as they were aware of the characteristic differences between the two main software programs that they had used during the project. However, this was mainly based on a practical context that is, the way they used them during their university education, because CAAD was introduced to students in a detached manner from its theoretical evolvement. SketchUp also intervened between sketching and AutoCAD in two staged process, this implies other differences in the mode of design exploration (2D or 3D). In recent years, studio studies (Dokonal and

Knight 2006) emphasised SketchUp as the preferred CAAD for conceptual design.

The discussion revealed that working with CAAD does not change the students' sketching habits and tendencies, mainly because of the characteristic differences and purpose for using either tool. Therefore, hand drawing will continue to provide a rough template for CAAD procedural steps but at the same time the act of drawing should be acknowledged for providing a better understanding of what has been drawn and the primacy of sketching will continue even in the digital age we are living in (Goldschmidt 2008). This should diminish educators' fears about substituting habitual skills.

In addition, the tutor's role as an influence on CAAD usage came forth. The students were asked not to use CAAD in concept design during different stages of their education. This influenced students' attitude towards CAAD and when it was allowed to be used in design. This concurs with Pektas and Erkip's (2006) study on tutors' attitude toward CAAD. However, this role contradicts another identified role for studio tutors - that is in appraising CAAD representations and their presentational quality. This brought subjectivity and confusion of architectural representations, which seems to be commonplace in architectural design. The quality of CAAD representations seemed to deceive the judgments systems of both students and tutors, this was claimed previously by Basa and Şenyapili (2005) and Knight and Dokonal (2006).

With regard to the studio process, CAAD was claimed to affect the design process timeline. Students' focus moved from concept transformation to CAAD practicality in reducing the time required to do the changes, without any other conceptual implications. This feature suggests that the number of changes that a student may undertake had increased, therefore, the continuity of the design processes in terms of changes and modifications rather than conceptual iterations. With respect to problem solving there was no CAAD contextualised implications. Instead, they related CAAD's ability in solving geometrical problems to other students within the class who they thought had better skills.

Most participants noted that the teaching of CAAD did not receive enough importance during their years in academia. They referred to themselves as a transitional generation as they had witnessed many changes at different levels of education and computer-aided architectural learning. It is of interest to consider the relationship between the time when CAAD was taught within the curriculum and when students felt they needed to use CAAD in their project and process. The identified gap suggests that students' needs were overlooked; therefore, forcing the student to learn CAAD in an isolated manner and learning CAAD became self-directed.

Another gap was identified with respect to CAAD development and workplace. Participating students had concerns that the rapid technological developments, and skills attained through education are developed over many years. Many of the skills acquired for professional development are attained through personal efforts after graduation. This suggests a gap existed in the way that CAAD is taught in architectural schools, not only in this critical stage of students' professional preparation but in earlier stages.

The aspects discussed were further corroborated in the research recommendations and implications for CAAD evolutionary learning, in section 10.7.

10.2 Protocol Study

The protocol study was employed to address the micro level interaction between the student and CAAD with respect to the following objectives:

- To provide an understanding of idea development while designing with CAAD representations with respect to CAAD's (current) characteristics as a design medium, and the impact of this on the individual design process,
- To improve our understanding of the relationship between imparting new media (CAAD) skills and "habitual" design practices.

In discussing the protocol study findings (Chapter 9), two points are considered: the collected design protocols represent *"designing…as a time sequence of activities"* (Gero and McNeill 1998 p.60), and as a *constantly evolving* conceptual structure or construct. Similarly, these two key elements showed that students (four participants) were able to create and maintain a representation of the design world where design ideas can be developed, to be described as c*o-operative behaviour* (Smyth 2000 p.34) with CAAD representations.

Both objectives were attainable through the investigated measures of the design process and design methods. These research measures were segment duration, number of design intentions, speed of thought and phase extensiveness. These are discussed next in the light of previous research.

10.2.1 Duration of Segments

To contextualise the CAAD design protocol findings within the larger body of knowledge, a comparison is based on the similarity of the methods used rather than the design situation (which CAAD is part of) therefore, previous studies on sketching provide the grounds by which to compare this study's findings. The basis for the comparison is the mean length of segments while using sketching. Under the sketching condition, the average length of segments (for six expert participants) was 21.5 seconds (Bilda 2006 p.47). In the current study, the mean segment length for all participants was 47 seconds, with the minimum segment duration of 4 seconds, and the maximum segment duration of 3.12 minutes. Sketching protocol studies report the average duration of segments ranging from 17 seconds to 23 seconds (Bilda 2006 p.47) and from 7.5 seconds to 37 seconds (Tang 2001 p.24). This suggests a longer segment within CAAD protocols, which is relatively high compared to sketching protocol studies.

Other studies indicate that the difference in the total number of segments in a protocol is based on the methodological aspect of the think-aloud methods. Concurrent protocol has a lower number of segments but longer than retrospective protocols (Tang 2001; Tang and Gero 2001). The average number of segments for this study is relatively low (72.75 segments) compared to previous studies, such as Bilda and Demirkan (2003) and Tang (2001), who used the same definition of a segment but recruited graduate students and experts. Another example is found in Tang's (2001) study of a novice design protocol with 142 segments. This is higher than the average number of segments reported in this thesis study. 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.

One methodological reason which can be added to the discussion is the data collection method used. Tang's comparative study (2001) of design protocols, found that the verbalisation method would affect the total number of segments, in other words, the number of segments in the retrospective protocols is higher than that in the concurrent protocol by more than a quarter (Tang 2001 p.24). The difference was based on the amount of extra time that was needed for verbalisation while designing, that is to complete the description of a certain act (drawing or talking).

According to Tang 2001, in concurrent thinking aloud sessions the participant tends to take "*more time to finish the description of an intention."* Tang's study did not support the idea that this extra time would interfere with the design process or concept formation (Tang 2001). Another reason is "*the interfering effects of simultaneous sketching in concurrent protocols*" (Tang 2001 p.24).

Other comparative studies of media transition, Bilda (2001) and Bilda and Demirkan (2003), have claimed that traditional media reveals more segments when compared to digital media. Furthermore, CAAD is part of the design situation, as discussed in sections 2.1.1 and 2.3. This also proves that the design medium and representation is part of the design situation, which Coyne, Park and Wiszniewski (2002) have claimed previously. The comparison suggests that CAAD based protocols have longer segments. Most of the longer segments are linked to CAAD - the procedural part of the intention rather than the conceptual part of the intention - however, designing preceded the proposal of a tentative (3D) design.

10.2.1.a Total duration and number of segments

The amount of time spent in design activity while using CAAD has implications for students' design behaviour. The design protocols varied in the total duration of the task and the number of segments (range of 14 segments between the shortest and the longest design task duration). The students tended to use one CAAD program (either AutoCAD or SketchUp) or two programs (both AutoCAD and SketchUp). The dependant variables for such tendency were mainly the student level of confidence in using a certain program, the phase of the design process (early phases versus latter phases) and the mode of interaction, whether 2D or 3D.

This brings the discussion to the shortest and the longest design protocols. These two design protocols are the most interesting among others in terms of the total duration of the generated protocols and the total number of conceptual transitions. The shortest design protocol had the largest number of segments such as participant SA2, who chose to start designing with AutoCAD and switched at a certain point to SketchUp. Switching between two CAAD software programs was one variation between this protocol study and the other studies. At the same time, the student approach within CAAD medium reflects a systematic progression from 2D mode to 3D mode with a continual exploration of the proposed design, that is to say the things (spaces, circulation, spatial relations, sizes and shapes) that he has solved on 2D level were explored further in 3D while using SketchUp. Working in 3D mode was not for communication or presentation purposes: instead, it was for active exploration of the decisions previously made and developed. On the contrary, the longest design protocol that had a relatively large number of segments (ST3), used one (Auto)CAD program. At the same time, the student approach within CAAD medium reflects traditional methods of visual thinking that imitates pen and paper from 2D mode to 3D mode. Design problem solving started on the level of 2D and was constructed in 3D.

With respect to the time spent in designing and the number of segments (transitions), Adams, Turns and Atman (2003 p.292) found, beside other criteria, that the amount of time spent in conceptual activities is generally linked to the success of the design (and therefore the design process). Moreover, they discovered that the number of transitions also correlates to the success of the result. If the task duration is taken as a criterion for design success, then the shortest task duration would imply that the design was not successful and the longest task duration would imply that the design was more successful. However, if the number of transitions is considered as the criterion then the shortest task duration with a high number of transitions (number of segments) would be better linked to design process success. The discussed perspective is compliant with Adams and Atman’s (1999) study and Adams, Turns and Atman (2003). This suggests switching to another CAAD medium could act as an intervention that would possibly affect the student's conceptual design positively within a CAAD medium.

10.2.1.b Speed of thought

Protocol segments documented students' shift of focus to represent one intention of the design process, whether conceptual, in terms of problem solving (design strategies) or practical, in terms of CAAD operative approach (draw, create, modify, etc.). There were two instances of correlation between segment length and their position along the design time line (process) to suggest that the segment length increases as the design session progresses. This implies that the speed of focus shift becomes slower with longer segments; however, this pattern was not consistent along the design process timeline or the design protocols. This means that whenever the conceptual design becomes more visually defined, the pace of change slows down, and students do not tend to make further changes. A blank view of the site would be more evocative than seeing what they have constructed or modelled. As a result, there are two aspects to consider: design constraints, and the richness of a representation. With time, the number of design constraints increases and becomes part of the design decisions and situation; these are documented in the design representations. The richness of a representation affects the student and slows down the process, as students should put more effort to handle all of them conceptually and visually. This is supported by Goel (1995), Bilda and Demirkan (2003), Stacy and Eckert (2003) and Haber (2003).

10.2.1.c Phases

In general, the early segments were rapid and shorter compared to the latter segments which implies that with time, the rich imagery of CAAD stopped students from making changes and continuing to change their designs. This also reflects the student dominant strategy in proposing a solution rather than using any other design strategy. These results concur with the vertical transformation notion described by Goel (1995) but also bring the individual design strategy to the surface. They are also proposing a solution which is related to clarifying a solution by detail or by repeating by copying or modifying. This is supported by with Bilda and Demirkan (2003) who claimed that CAAD works by the "*draw and* *then modify*" principle. However the current study findings provide a deeper insight into these actions through the process-oriented coding scheme. To deduce what is happening whilst using draw and modify on the conceptual level is of key importance, not what is happening on a technical level. The participant who used 3D (SketchUp) mode extensively not only copied or repeated the former shape construct but also used different procedural steps to reach a similar visual construct. The form which he transformed again on one corner of the building was the same abstraction/concept used or applied on the other corner of the same building but he drew it differently, that is reflecting the same idea of having a smoothed shaped square at the corner of the building but drawn differently. Thus, modification in computers is not only about copying the same object but also about reusing the same operation, for example in drawing a design, especially if he had failed to draw it correctly the first time.

10.2.2 The Design Process

This section discusses the descriptive analysis of CAAD drawings in section 4.8.1. The drawings produced in CAAD protocols can be described as dynamic in following a certain course of action and rational inference. This would comply with most conceptual drawing studies (Akin and Lin 1995 p.58; Goldschmidt 1994; Tang 2001). As such, CAAD drawings enable both novel and routine tasks, which are required technically to acquire information (calculations, sizes, shapes, relations and heights) or stimuli.

Some of the common conventions were observed such as 2D diagrams, elevations, sections and isometric models, agreeing with Do's (1998) effort in categorising drawing conventions. Moreover, providing the students with CAAD site representation clarified most of the site information, design constraints, for example trees, the river, orientation, circulation and the surrounding buildings. Most of the participants used these conventional drawings because they started with a 2D mode and proceeded to 3D mode (apart from ST3 who used 3D mode from the start). In general, design representations evolved in a linear manner. There was no instance of going back to 2D diagram to modify it conceptually after advancing to 3D modelling in participants SA1, SA2 and ST3. The observations showed a sequential relationship between the different types of drawings used.

Observations of the methods used by the students suggest that CAAD may change the design process, which also suggests that CAAD is different to sketching. If students used it regularly in their design processes, they might develop new strategies and change their familiar strategies into unfamiliar regardless of its efficiency or reliability. This supports Coyne, Park and Wiszniewski's (2002) study with respect to the combination of traditional and digital methods in drawing, which is that each are valued rather than replacing one another. This gives some insight into the potential change in the design process using CAAD or digital media with regards to supporting the theoretical propositions of theorists like Oxman (2006, 2008), and studio instructors like Al-Qawasmi (2005, 2004) and Dokonal and Knight (2006).

10.2.3 External interactivity

In observing students' engagement in the drawing process (whether by drawing acts or visual engagement), there are many observations made with respect to CAAD representations and visual stimulus and feedback. The visual stimulus of CAAD representation was high as all the participants showed a conceptual tendency to adopt visual or spatial elements of the given site CAAD representation. SA1's proposition was based on relating the site to the surrounding buildings by suggesting a triangular shape that imitates the space among the three surrounding trees to change the state of the design situation and work on its development. SA2's proposition was based on imitating the conceptual structure of the whole campus, where he decided to have a similar structure but on a smaller scale that suits the site by having a path that links the different spaces within the site. ST3 used a similar strategy to SA1 but did not use the trees as points for the resulted layout, but by adding two different shapes to comply with the surrounding trees as constraints. ST4's proposition was based on replicating the shape of the surrounding building of Gray's school, where he took the concept and the shape of a courtyard. The visual connection between imitating what is there in reality (the building on site) is in agreement with the mode of externalisation (3D mode).

The given representation affected their starting point. Whether this related to their individual design strategy or others requires more investigation, but surely using CAAD affected their initial start and was based on its visual quality as well as its conceptual content. These visual constraints have conceptual meaning and the student constantly revisited them as static elements or constraints that he/she had to deal with while solving the design problem.

Another observation was the software nature and its visual feedback. The student (SA2) who switched from one program to another was more likely to experience sudden discoveries (new visual insights) than the other three 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 SketchUp mechanism in subtracting geometrical volumes while drawing an intersecting 3D object (Boolean operations). Design exploration 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. For example, in SA1's protocol the central hub was mentioned before deciding on the place of that hub in relation to the surrounding spaces and the visual configuration.

Another observation was the methods that were used by the students. For example, the student who started with 3D SketchUp from start to end was more likely to confront and retract some of the decisions that he had made earlier and solve them on the level of 2D in his imagery and by calculating the required spaces (brief in relation to the drawn objects). This student showed many differences in thinking, design process and using CAAD.

10.2.4 Coding Schemes

The participant engages in one type of drawing and mode (2D/3D) for a series of segments whereby he uses one type of drawing for exploring different design micro strategies while considering more than one level of abstraction. The analysis of the design micro strategies in section 8.5.2 showed two main points: individual differences are apparent between the four participants, and most of the time students spent designing in CAAD was based on proposing a solution more than any other design solving behaviour. The former point agrees with studies that emphasised the individual differences in using various design strategies of problem solving (Bilda and Demirkan 2003; Liikkanen and Perttula 2009; Eisentraut and Gunther 1997). The difference in strategies arguably changed the course of the design process (Eisentraut and Gunther 1997; Eisentraut 1999). This was also reflected in the variety of time spent, and representation types. The latter point agrees with many studies (Lawson 1979; Restrepo and Christiaans 2004; Kruger and Cross 2006) that describe design in general, and novice design process, in particular, as solution-oriented. A recent study by Liikkanen and Perttula (2009), involving 16 senior students of mechanical engineering, evaluated the occurrence of problem solving modes using think aloud methods and found that designers tend to refer to solutions explicitly rather than problems in the collected protocols. Comparing the time spent in problem analysis in Tang and Gero (2001) also shows a similar trend of less analysing activity compared to the other two micro activities.

Based on the findings of the two analytical approaches, design process oriented coding and linkography, the early phases are the most intensive phases of the design and are the most reliable for the latter phases. This resembles previous studies in sketching. For example, Tang and Gero (2001 p.287) have suggested in a comparative study between concurrent and retrospective protocols, that concurrent protocol reveals more information at the start of designing compared to retrospective protocol. This information was focused on the design problem and formulation, as the student tried to conceive the problem first then build his consequent behaviour (Lloyd, Lawson and Scott 1995). This information was subsequently externalised through drawing.

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. One example is provided by SA1 who asked a question that could not be extracted from the given drawings so he drew a section (to know the height between the proposed building and the upper path of the site) which enabled him to make a subsequent decision (to tilt the roof). Another reason can be the level of site familiarity as it is part of the campus and adjacent to their school, so the students perceived the design situation more easily. In the experimental design, it was intended to minimise the uncertainty level of the design condition.

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, the participants spent relatively more time considering level 4, to suggest that the level of CAAD detail has occasionally shifted the participant'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.

10.2.5 CAAD impact on self-communication

Protocol study analysis and discussion can be further categorised into deviated protocols, shift of intention, and a discovery moment. These are described further in the following sections:

Deviated protocols: there were instances where all four participants deviated from content towards CAAD operative moves; however, these occurred in leaps rather than loops of deviation that is a thought sequence completed after the leap (leap of procedural acts but loops of conceptual thoughts) and thus can be described as interruptions.

Shift of intention to character evaluation rather than conceptual judgement. Shift to detail through considering the detailed level of CAAD representations. That is to say the student had considered lower levels of detail of the representation. This was also reported by previous studies, Goel (1995), Bilda and Demirkan (2003), and Dokonal and Knight (2006) although the investigation conditions and settings were different.

Discovery moment came when the change of the program occurred (in one of the analysed protocols). In the debriefing phase, the participants mentioned that they

were able to imagine their ideas representation in 3D (design world) but the imagined 3D constructs were not finished. The visual interaction with CAAD representations helped them to visualise and realise the final state of these imagined constructs. The moment of new insight was argued by the participant with respect to authorship and CAAD automated effect. It was not acceptable in terms of who did the action. This was the first time that the student encountered such an experience. The question is when these insights become part of the conservative utility of CAAD representations will it become more acceptable?
In another study, Al- Qawasmi (2005) describes the digital design process in the e-studio as a model for fluid-thinking mode that is *interactive*, *integrative*, *reflective* and *immersive*. Similar characteristics were observed in this study; however, the experimental condition was another effect on their thinking. The design process can be described as conversant with the design problem which was also confirmed by the linkography methodology.

Furthermore, Linkography analysis suggests that CAAD affected students' conceptual content in two ways: (1) participating students revised and repeated their ideas more than proposed new or different ideas, and (2) for an extent made the students less inventive in terms of number of options, however, the nature of the task and the time required to finish the experiment should be considered. These points agree with Goldschmidt's definition of the backward and the forward critical moves (1995 p.205-6), and Bilda and Gero's (2008) definition of links density.

This suggests that from the start of designing, most of the participants started to externalise their ideas, whether through CAAD or words to reach a tentative solution to the design problem. Also, it suggests that the initial ideas are deemed to be the most successful, which are often revisited and developed. This is similar to designing under sketching conditions.

10.3 Triangulation of Findings

Many studies, Bilda (2006), Bilda and Gero (2005) and Tang (2001), have explored *actively* designing behaviour (participants) while interacting with sketching as part of the design situation and claimed *passively,* (that is without considering CAAD as part of the design situation) various implications for CAAD within the conceptual phase of designing. Instead, the current study provides an active exploration of CAAD in the conceptual phase of final year students' design process to suggest new insights into what relationship CAAD should have with architectural design education.

The survey, studio reflection and design protocol studies were utilised to understand the current role of CAAD in architectural design education of final year students, on two levels of their design activity: on the macro level of interaction among students, tools and project model in the studio context and on the micro level of interaction among the student, CAAD, and design brief in the individual design process.

Thematic similarities in the findings of the three main studies were revealed. These are presented in this section. The data collection for this thesis took place over a three-year period at different intervals. Despite the rapid developments in CAAD through that time, such as, digital sketching based software (Autodesk SketchBook pro), or other interface modifications that enabled sketchy CAAD drawings, which were embedded in the available CAAD versions (SketchUp and AutoCAD) and available for the students to use (through Autodesk students community), in general, there was no change in the sample's views. However, changes in viewing CAAD as a designing tool in concept design were documented as a result of actively probing the status of CAAD through the studies, especially through the focus group and protocol study. Thus, changing how CAAD is perceived by final year students is a difficult task. Therefore, the most important aspect in perceiving CAAD as a design tool is the pedagogical approach and the teaching context, ahead of available infrastructure.

10.3.1 CAAD program dominancy

In common with the results of the first (descriptive survey - Chapter 6) and second (studio reflection - Chapter 7) studies, the design protocol also suggested that AutoCAD is the most widely used program in the architectural school by final year students. This corresponds with many CAAD oriented surveys, such as Penttilä (2003) with regard to European schools of architecture, and Dokonal and Knight's (2008) survey of the European professional practices. Both studies suggested that AutoCAD is the dominant tool in both settings. This is based on employability factor; student's preference to learn one of the programs at the expense of the other (Garcia et al., 2007) depends on what is used in industry that is professional systems. However, Schenk (2005) voiced a warning comment regarding the dominance of a single program and it seems in its place after all. In that respect, breaking such kind of dominancy would be in combining various CAAD programs within design in particular programs with different characteristics, such as SketchUp.

Another example of AutoCAD dominance was apparent in students' terminology. The focus group discussion revealed that when the term CAAD is mentioned, the first package students would think of is AutoCAD (see section 7.6.2). Also, they tend to separate what is termed CAAD into components, mainly into three different packages: AutoCAD, SketchUp and Photoshop. Thus, CAAD as a generic term, does not exist for students, and is purely practice based. The separation of CAAD into different packages occurs when a specific program is needed and used to reflect the variation that each may provide.

Few students proposed that SketchUp characteristics could be more suitable for design exploration than AutoCAD, and referred to a point in the design process just after the concept and before moving to CAAD when SketchUp is more suitable for seeing and testing the first (tentative) design concept(s) for its third dimensional aspects. SketchUp had been positioned in-between conception and CAAD, somehow bridging the gap. Students viewed Photoshop as a professional system which would complement CAAD's "soulless" character. This supports Basa and Şenyapili's (2005) study of CAAD's presentational characteristics within student design process and jury presentation. Using an editing software program alongside AutoCAD helped the students to add character (rather than 2D working drawings). This indicates that presenting design has moved beyond hand drawing to be totally produced in CAAD as opposed to Basa and Şenyapili (2005) who reported that students preferred presenting hand and hand-CAAD combined drawings.

10.3.2 Designing or drafting

Defining CAAD as a drafting tool or a designing tool, section 6.2.3 (figure 6-10), demonstrates either the dual meaning for both activities, or the dual purpose of using CAAD. Either way, CAAD is considered mainly as a drafting tool. However, in the focus group, the discussion revealed that students view the two as inseparable acts or a "*mixture*". In other words, one would lead to the other. The other key factor here is the process of transferring what is constructed mentally by the students; that is blurred and uncertain, into communicable ideas. This is seen as a complex process that students face (Ambach 2006 p.217). In the protocol study, the students showed a clear ability to manage such complexity in CAAD representation. The students externalised their mental model(s) of abstraction and interacted meaningfully with the legible part of the same construction (proposition). This is another reason for combining CAAD and hand drawings. The move to another medium suggests a need for other characteristics; therefore students should be experienced enough in various design media to recognise what is required for design problem solving at a certain moment in the process timeline. As such, students' ability of media critical assessment is important to facilitate the changing status of a design situation.

10.3.3 Skills and knowledge

The findings suggest that even when the students are in their final year and use CAAD on a regular basis; it does not mean that they have the right skills for designing with CAAD, as they lack knowledge along with the practical skills. Coyne, Park and Wiszniewski (2002) emphasised the same point, in that designing with CAAD is limited when there is no adequate experience to enable designers to explore CAAD's capability: ''*If you only know how to draw a box, your building will be a box, and if you know how to design anything on the computer you can design anything*'' (Coyne, Park and Wiszniewski 2002). In a recent study, Pektas (2010) suggested that novice students' capabilities are limited by their design tools use. Learning digital skills (skills access) should be supported by a positive mentality (Meneely and Danko 2007) regarding the use of CAAD in design, and this would occur through the usage access to a number of CAAD systems that vary in nature and facility. The survey results may suggest that the students are motivated with a highly positive attitude, suggesting highly evolved design practices from the students in the studio, but the studio reflection study clarified the survey propositions. The detailed picture of these skills and their usage shows that they are not significant to design thinking, but very important for the practicum of architectural design. At the moment, these kind of digital skills are only enough to interact with the digital media on the surface level of the visual representation (Oxman 2006), imitating the traditional methods of designing.

As a result of the focus group discussion, it is clear that tacit knowledge of design structures plays an important role not only in the conceptual design but also in design and its impact on promoting CAAD use. By this claim, another meaning is added to medium flexibility. This also reflects the students' lack of connection to CAAD as a tool for the conceptual content of architectural projects. CAAD teaching should create a balance between *how* and *what* to design through 2D or 3D manipulation and visualisation.

10.3.4 3D Conceptual design

Throughout the survey, the interviews and the focus group, the participants showed a tendency toward using CAAD as a tool to investigate a specific conceptual theme (formalism, form generation, geometry). The CAAD medium is able to relate to the participant's design interest in architectural geometrical formation and the conceptual process.

Students with interests in design formation studies (form generation) tend to use CAAD, whatever level of CAAD skills they have. Two instances (ST4 skilful 3D CAAD student and Sb2 skilful sketch student) were found in the studio reflection and the protocol study. Such tendencies need to be questioned systematically through integrating CAAD into the project model of the studio. Providing such knowledge to final year students is crucial for their practice. It is argued that when design graduates become designers in industry they use the same methods that they learned during education. Thus, lack of skill and its relationship to knowledge could affect their confidence, which they need to bridge through learning during practice. Thus, CAAD situated knowledge becomes part of their success in real life practice, which can be enhanced through using design tools in a design: situated manner through case studies from the real world.

Some computer usage aspects were common between the studies, such as frustration as the discussion group mentioned that CAAD "*is frustrating*" (P6) and the rest of the students agreed. Frustration was mentioned in relation to the slow computer hardware, and was also related to the slowness of the tutor when explaining a CAAD tutorial. Thus, this frustration is a result of the teaching experience as the students' could not interact at the same time as gaining the information. They did not have access to a computer to do the same as the instructor. This frustration was also observed in the protocol study but in a different way, when the participant expressed frustration noises while designing (and failing to zoom) with CAAD then saying that: “*it is playing games*” (SA2).

With respect to the duration of segments, participants designing with CAAD representations (design protocols) tended to have a lower number but longer segments compared to sketching design protocols. CAAD is praised in the literature for being quick and easy during designing. This study would further argue that there is a contradiction between how CAAD exactly influences the designing process of students individually and the design process in general. This raises the question; does describing CAAD as quick and easy imply that students are using it on the surface level with respect to design tasks, process and methods? Findings in this research have answered this question by investigating the CAAD role in different intervals of the design process of the studio model.

Another aspect could be that the immersion that is felt and reported by other studies (Al-Qawasmi 2004, 2005) is the reason for describing CAAD as a quick tool for design. This was also felt by one of the design protocol participants as the student felt that the time flew when he was working with CAAD. If the student was working on a design then this feeling might be related to immersion rather than time passing quickly*: “I think it was quite simple and time flies when using AutoCAD, it really does, when you are busy and thinking as well it seems quarter an hour rather than an hour” (*SA1 debriefing clip). Thus the nature of the design task and the relevant CAAD mode or representation should be considered carefully in interpreting CAAD speed in relation to conceptual design.

10.4 Conclusions

The research aim has been to understand the current role of CAAD in final year architectural design education and CAAD impact on visual thinking. This aim was explored on two levels of student design activity: on the macro level of interaction in the studio context, and the micro level of interaction in the individual design process, whereby a mixed method approach was employed to achieve the following objectives:

Final year Students

1. To improve our understanding of how final year students perceive CAAD in the final years of architectural education.
2. The role of CAAD educational methods in the way it is used by final year students.

Studio

3. To improve our understanding of the role of CAAD programs in the traditional design studios.

Individual

4. To provide an understanding of idea development while designing with CAAD representations with respect to CAAD's (current) characteristics as a design medium, and the impact of this on the individual design process,

Studio and Individual

5. To improve our understanding of the relationship between imparting new media (CAAD) skills and "habitual" design practices.

These were achieved through documenting the student's design activity (process) on two levels: the students' individual design activity (reflection in action) and the students' design process within the studio context and educational constraints. As a result, understanding of the role of CAAD educational methods and its utilisation in conceptual design will be improved during the early phases of designing.

10.4.1 Contribution to studio macro level of design interaction

The research contribution to existing knowledge concerns the relationship between final year students and their tools with a specific focus on CAAD professional systems in two contexts: architectural studio and individual design process.

On the macro level of design activity, the role of CAAD programs in the traditional design studio was examined through **the studio reflection study (study one, two, three and four)**. This study aimed to explore how final year project model and teaching methods were influencing CAAD usage in the traditional context by final year students. Analysing this relationship through design activities in the studio has revealed the controlled status of CAAD in the architectural design studio. It is controlled by other variables besides its characteristics; variables that are based on the **project model**, **tutors** perceptions, skills and **habitual** practices, and by the constant comparison to other thinking tools that is very different from CAAD.

The **project model** mostly controls students' interaction with design media in the studio, especially in the early phases of the studio design process, when the pedagogical aspects of design media are of greater importance than other aspects. The traditional model of studio teaching provides a typical context to study architectural design, but has missed opportunities to cope effectively and overcome contemporary issues of architectural design and the digital divide, as there is no planned integration for CAAD within the project model. Therefore, the case study showed that The studio context implies many restraints that are identified with respect to students- media/tool and tools–project interactions. Media interaction is not spontaneous as it was proposed earlier (before undertaking the study). There is a pedagogical agenda for media interaction that is instructive rather than explorative. The findings showed **that tutors** should not be fearful of the use of CAAD in the conceptual design phases of studio projects, since students simply regard it as an additional tool. The students identified the effect of CAAD on their design processes mostly in terms of presentation, and speeding up the design process.

In addition, habitual practices are favoured and encouraged over new media practices. However, small changes in the habitual practices may bring a change of perception as well as new practices. Apparently CAAD is mainly used on the surface level of drawing in 2D; that is external interaction, however, the case study provided a practical context for CAAD application in the traditional studio compared to the survey. In spite of this, CAAD has expanded the conceptual sketch by checking and straightening the conceptual design early in the process. It has also expanded the conceptual phase of design by (CAAD's) two characteristics: ease and speed of use. This provided more time to iterate through a variety of mediums not only within CAAD. By these two means, CAAD has supported the students to develop new ways to understand and visualise the design. This may promote new patterns, relationships, or aesthetics rather than limit creative solutions (Jonson 2005). However, the students are reaching a threshold point between routine tasks and creative tasks but as they do not have the required base for knowledge to take action, they stop and return to the traditional methods. The findings also recognised that there is a gap between the time of teaching CAAD, which is often used in the early stage curriculum, and the time when CAAD is needed by the students to manage the complexity of the given project.

This study has contributed to a deeper understanding of CAAD as a representational tool that is evolving into descriptive knowledge of design methods and processes that should be considered as an integral part of the architectural design knowledge and the project model.

10.4.2 Contribution to design activity micro level of interaction

Analysing this relationship through the individual design activities revealed that if CAAD was used in concept design this may impart changes on the personal design methods, design process and visual thinking. Interacting with CAAD spontaneously is needed to develop student's critical ability of the tool used. The protocol study has contributed to a deeper understanding of how CAAD may affect students' thinking and eventually overcoming limitations in strategic awareness and enhancement through increasing the flexibility of students thinking.

This study acknowledges CAAD representations as a conceptual medium rather than a drawing tool that has a distinct character from other tools and media. Visual thinking through CAAD representations is similar to that of traditional representations, but can provide a deeper (external) interactivity via 3D modelling and virtual exploration. It also acknowledges that CAAD may influence thinking in a certain way but does not hinder it, especially when a combination of tools or CAAD software programs is employed. It verifies student's thought speed and shift of intention in different ways to conclude that the designing process is time consuming as CAAD becomes part of the design situation. This idea is opposed to the prevalent perception of using CAAD in the design process. Shift of intention is concerned with level of abstraction, practical and technical system failures which are temporarily manageable through greater awareness of their potential impact on the individual design process. High confidence in CAAD might bring new practices to the design process such as starting from 3D modelling rather than 2D spatial design. Other modes of external representations such as verbal thoughts aided the design process and thinking while designing with CAAD.

On the micro level of interaction (protocol study), every participant solved the design problem differently. However, traditional design methods were common compared to other methods that are CAAD bounded. These traditional methods include 2D conceptual exploration at the earlier phases, 3D conceptual construction at the later phases, and the use of orthogonal drawings. Drawings (representations) are used in the design process not only to represent but also to elicit missing information or see a particular design intention. Hence, the use of familiar methods that the students had been taught were prevalent to resolve the spatial and functional requirements in a traditional way. These design protocols reflect a comprehensive approach in dealing with the aspect of the conceptual design and functional / spatial requirements / problem solving. In addition, they are traditional in using a 2D mode of thinking at the beginning of the design, except for one participant who started drawing in 3D isometric mode and instantly extruded the 2D shapes into 3D volumes. Even if the drawn element is in 2D (area, sizes, shapes), the principal feedback was from 3D mode rather than 2D. The change in mode was significant in changing the methods of problem solving but not necessarily for the better. In addition, the interplay between two CAAD programs showed a significant impact on the student's design process. Again, this study was able to categorise the impact of CAAD on the individual design processes into six different effects, shown in section 8.5.6. Knowing these would raise students-tutors awareness of the probable impact while using CAAD for designing, through which new strategies could help students and tutors overcome similar effects.

It is clear that CAAD as a domain is more than a tool for designing or presentation. In light of the 21st Century challenges of higher education, CAAD becomes much more critical as a knowledge base. The studio context is still the most vital medium for architectural design learning and knowledge integration (knowing in action). Recent claims emphasised trans-disciplinary knowledge integration into the studio context (Salama 2008), taking students' needs as the main criterion because it would be more effective to channel students' efforts toward their needs (Kuh et al. 2010).

10.5 Recommendations

This thesis was able to clarify the effects of CAAD on the traditional context of the architectural studio and on the individual design process. How to reflect that within the teaching method should be considered through the primacy of drawings as a medium for design. Building student's skill is the first step towards CAAD integration as a designing tool. As a result, a number of recommendations are put forward:

- Consider CAAD as an important part of the social and cultural impact of computers.
- Consider CAAD as a knowledge base that consists of *why*, *what* and *how.*
- Promote tutors' attitude towards CAAD through new structures of knowledge that is embedded in precedents from architectural practice.
- Tutors should at least hold a positive attitude toward students' use of CAAD by knowing the potential benefits of CAAD within the studio project and how this can be related to students' differences in skills and abilities.
- Encouraging discussions while working on CAAD would bring the studio dialogue to the context of CAAD in concept design.
- Integrate CAAD as a designing tool by moving forward from the prevalent skill of 2D CAAD into 3D CAAD, where CAAD becomes a medium for exploration rather than production.
- Promote a visual enhancement through CAAD representations which would enable the move beyond how it looks to why it looks like that.
- CAAD representation should be paired with design problem solving, and contextualised in design studies as a new design language, and should not be alienated from other design media interactions, either to complement or to contrast.
- Breaking the polarity of one CAAD system in education is important beside the regular exploration of CAAD advancements in architectural practice and software.
- CAAD learning and teaching as a design tool should be handled within the design curricula rather than ITC in a partnership (Reffat 2007).
- Adapting the curricula and exercises to students' needs and the project model (size and type) rather than suggesting a role that is drafting/ presentation-centred.

- Establishing a framework for CAAD expertise development that continues to feed into students' practices until the final stages of architectural professional education, using differences in focus, complexity and level of CAAD interactivity through a variety of training modes: workshops, online tutorials and case studies.
- Using the tool will help the student to be critical on when to use it and what for.
- Using CAAD freely is a self-centred skill that is learned through trial and error within an extensive period.
- Students should be aware of CAAD's potential impact on thinking to overcome it by combining another type of software or other kinds of media.

10.5.1 Implications

A holistic view of the research findings suggests that for most (final year) students, learning CAAD has become self-directed. To an extent this is true (according to van Dijk 2005), as it is based on software learning rather than on a design contextualised approach.

In line with recent calls for empowering students dependency by managing studio-tutor relationship and informal learning (McClean 2009); if students' positive attitude toward technology is utilised, then learning can be gained through personal empowerment to bridge the gap of digital skills and knowledge by providing instructional guidance that complies with their needs from the initial stages of their learning. An integral approach is proposed to determine students' personal needs and by building appropriate learning situations to meet them. By appropriate learning situations this means that it is design problem based rather than software based and rich in the context of problem solving and design inquiry.

Student's needs should be developed through time and process before they can be identified. After placement and before graduation it is a suitable time and stage to stop being concerned about students' abilities and traditional methods of understanding and design cognition development which are extensively emphasised in the earlier years of architectural education. This turning point is seen as appropriate to evaluate students' skills to identify what is needed for their professional development, to set goals and objectives, which at the same time will cope with technology rapid development as it will provide students with up-to-date application between practice (placement) and academia, taking into perspective the most recent trends in teaching CAAD and CAAD-evolving knowledge.

In essence, choices should be made to engage students in terms of approaches, sources and techniques with respect to the identified needs. For example, approaches may include in-studio workshops, professional CAAD lectures of leading architects or practices, or studio project. Sources may include research based case studies or teaching based case studies, and techniques may include CAAD tutorials, online forums, or CampusMoodel.

This study found that CAAD in later years of education had become a self centred learning, therefore to promote CAAD education (in the light of Mark, Martens and Oxman's 2003), an interactive cycle of student skills development is proposed. This interactive cycle aims to build up students' awareness of CAAD's potential effects and pitfalls whether processing design on the macro level of studio project or on the micro level of self-communication process. A six steps cycle is proposed for CAAD's skills and knowledge development that starts with students' input (needs) and ends with students' outcome. The cycle consists of the following steps as illustrated in Figure 10-1:

1- Creating a positive learning environment that accepts CAAD as a design media for any time in the design process. Needs are then identified with respect to the cohort.
2- Evaluating the cohort diverse levels of design skills through which CAAD is part of.
3- Practical evaluations of students' design skills and knowledge.
4- Setting objectives.
5- Proposing an appropriate learning situation.
6- Evaluating the outcome which will feed into next year's (stage) cycle.

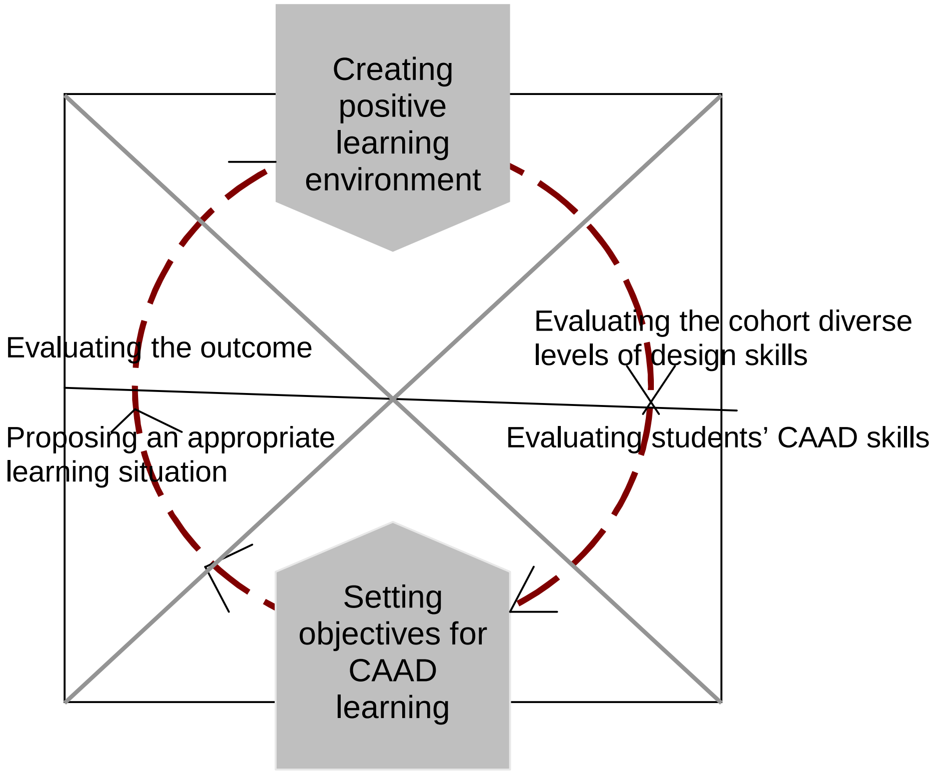


Figure 10-1 CAAD Professional development.

The last feature that this cycle may enhance is professional CAAD development. The most important start for this cycle is creation of a positive environment for CAAD and one way to do this is to involve both tutors and students in the same cycle, through which there is much to learn from each other (tutors and students).

This research focuses on professional development of final year students at SSS with regard to computer-aided architectural design systems. Final year experience is critical to the development of students by providing the knowledge necessary for this transition to take place with confidence. Experience gained from the final year study is significant to graduates' working life and career, and it is hoped that graduates have learned the skills necessary for their practical application in the future.

10.6 Limitations of the Research

One of the limitations to this research could be one institution only case study. The findings may be tinged by the educational approach practised in the School and the case study approach. If, for example, students studied CAAD through a different pedagogical approach and setting (with a CAAD-positive attitude in the early phases of concept design) then the results could be different, and other insights may be discovered. Moreover, another study could expand to include students from other design institutions or disciplines, possibly an artistically based institution that encourages the exploration of media whether traditional or digital, and may be accompanied by the analysis of teaching and skills assessment methods.

Protocol studies' methodological limitations can be in the time required not only for analysis but also data collection. Although the same procedural steps are followed, and the same level of expertise is targeted (sample), it is problematic to obtain design protocols with the same or similar degree of verbal/visual quality so the generated protocols varied qualitatively and quantitatively. This may be related to the expertise model of the participating students as most published protocol studies utilised participants with high-level expertise (Jiang and Yen 2009), that is expert designers. In addition, recruiting students with an interest in using CAAD for concept design was one of the limitations within the school; the other limitation was non-native speaking students who found it difficult to think aloud during designing. However, a sample size of 1-3 is acceptable in most published protocol studies (Jiang and Yen 2009). In general, recruiting students could be moderated through an enthusiastic environment for CAAD research and exploration in collaborating with studio instructors and a project model.

10.7 Further CAAD Oriented Research

New research is therefore required for analysing the switch between two different CAAD software programs and whether more general findings may result or triangulate. Analysing the switch between traditional and digital media has been examined thoroughly (Al-Qawasmi 2005; Bilda 2001; Bilda and Demirkan 2003; Coyne, Park and Wiszniewski 2002). Accepting the differences between the two media will shift the argument further to explore the switch between various digital media programs and a combination of other tools for design thinking.

The validity of CAAD phased training (versus a sample's longitudinal training/ gained knowledge) of research design and its findings, and whether the desired level of CAAD technical proficiency was achievable through this method is questionable, as these studies never looked at the methods used in the training sessions and the way their sample used CAAD during experimentation. This takes the discussion to precedents in design, and architectural design in specific. In studying CAAD's impact with respect to the architectural precedent role in designing, we are prompted to ask the question: what is the conceptual impact of such precedents? These precedents are becoming accessible on many levels: 3D models as well as two dimensional images of the mode. This shows us how the design process is communicated and how the design methods are learned.

There will always be students who will excel either in traditional or digital design methods, or both. In order to carry out more in-depth research, it might be necessary to provide further participants with certain representational behaviour that will reflect design skills, representational skills, and a visual preference or reflect other spatial abilities. To define such a relationship between the two would require a longitudinal systematic study that focuses on these skills and behaviours (performance) and would provide new insights for educators and studio tutors about students' differences and how CAAD may help to overcome these differences. In the same line of thought, studying the professional expectation of final year students to the gained experiences from a new study would provide new insights on the sample's needs and also, how could we employ placement to force graduate attributes.

After realising the impact of CAAD on architectural design and design education in general, we turn to design research and its impact on finding a common ground for similar studies that are comparable on a more specific criterion. Studies are needed with clearer terminology, which is practice dependent, rather than based on theoretical propositions. There is often a problem in the terminology used within CAAD research, which must be overcome to address subjectivity of design through research objectivity.

This research highlights the need for more research to study the strategies employed by designers when they use CAAD and calls for more formal, objective CAAD studies to improve architectural design education through experimentation (practice based cases). Moreover, in the same context of architectural education and study findings there is a continuous need to explore tutors' attitudes towards CAAD and its changing role.

To some extent, the research undertaken in this thesis bridges the gap between CAAD passive research and design (process) active research. Further CAAD research would necessitate a continuation of CAAD research to enable comparative studies, which would reduce the subjectivity in architectural design in general and the used methodologies in studying design activities in particular, for example protocol study.

The fact that CAAD representations have affected students' design process by providing visual stimulus for their design concepts should be investigated thoroughly. Does CAAD representation make designing contextualised when it is compared to other types of representation? It is necessary to investigate CAAD's representations in more depth in relation to visual stimuli design studies and how it could affect the mental constructs of students and design processes.

One of the future challenges is new undergraduates (with a potential interest in studying architecture) who are fascinated with computers in the same way as we loved drawings and sketching years ago, forming an important part of why we wanted to be architects and designers. Arguably, future generations will be fascinated with computers alongside architecture. Such students will know more about computers and CAAD than designing.

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Appendixes

Appendix A: Publications

SALMAN, H. S., LAING, R., and CONNIFF A., 2008. The Changing Role of CAAD in the Architectural Design Studio. *The Built and Human Environment Review* [Online], 1. pp. 25-39. Available from:
http://www.tbher.org/index.php/bher/article/view/5/3

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Appendix B: Questionnaire survey supplementary material

B-1 Questionnaire A (2005)

Introductory Remarks

- ***CAAD*** refers to **C**omputer **A**ided **A**rchitectural **D**esign.
- ***Early design phase*** refers to: Design brief analysis, outline design and final sketch design.
- ***Final design phase*** refers to: detail design.
- ***Medium*** refers to the visual communication methods or the actual hosting environment through which the design thoughts and ideas evolve.
- ***Visualization*** refers to the ability to create mental pictures which lead to the development of a design solution.

Section 1: Participant's Background Information

Gender ☐ Female ☐ Male

Age ____years

Section 2: Participant's General Architectural Design Experience

Q2.1 As an architect how do you rate your skills in the following;

a My skill in architectural design is;

☐ Poor ☐ Fair ☐ Good ☐ Very good ☐ Excellent

b My skill in sketching is;

☐ Poor ☐ Fair ☐ Good ☐ Very good ☐ Excellent

c My skill in CAAD is;

☐ Poor ☐ Fair ☐ Good ☐ Very good ☐ Excellent

Q2.2 Would you like to improve your CAAD skills?

☐Yes ☐ No

Please explain your answer.

Q2.3 How did you obtain your CAAD experience? (tick as many as apply)

☐ University course ☐ Private course ☐ Personal effort

Q2.4 How would you describe your use of CAAD in the architectural design process?

☐ I never use CAAD [**Please answer section 3 only].**

☐ I am aware but I have never used CAAD [**Please answer section 3 only].**

☐ I only use CAAD sometimes [**Please answer Q2.5, then go to section 4].**

☐ I use CAAD on a regular basis [**Please answer Q2.5, then go to section 4].**

Q2.5 I use CAAD in the

☐ Early phase of the design process (Design brief analysis, outline design, final sketch design).

☐ Final phase of the design process (Detail design).

☐ Both phases.

Section 3: **CAAD non – users**
[*only fill this section in if you never use CAAD*]

Q3.1 Please explain why you don't use CAAD in your design process.

Q3.2 How likely are you to use CAAD programs in the future?

☐	☐	☐	☐	☐
Very Unlikely	Somewhat Unlikely	Not Sure	Somewhat likely	Very likely

***Thank you for your participation. Please note that you don't need to answer the rest of the questionnaire*.**

If you do use CAAD, please continue with the rest of the questionnaire.

Section 4: **CAAD Use In The Early Stages Of The Architectural Design Process**

Q4.1 Would you use CAAD as the **sole medium** in any of the following conceptual design phases? (tick as many as apply)

- ☐ Design brief analysis
- ☐ Outline design
- ☐ Final sketch design
- ☐ None

Q4.2 During conceptualisation, does using CAAD help you to (*tick as many as apply*)

- ☐ Understand my design better
- ☐ Communicate my ideas to others
- ☐ Express my ideas better
- ☐ Understand the design brief
- ☐ Straighten up my pre-conceptual ideas
- ☐ Identify design problems successfully

Q4.3 "Using CAAD within my conceptual design affects my work positively." Do you agree with this statement?

☐	☐	☐	☐	☐
Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

Q4.4 Please specify in which ways you think that using CAAD affects your work.

Q4.5 Which of these CAAD programs do you use?

☐ Auto desk VIZ	☐ Auto CAD
☐ Architectural Studio	☐ 3D Max
☐ Rhino 3D	☐ ArchiCAD
☐ VectorWorks	☐ Microstation
☐ Sketch up	☐ Other , please specify;______________________

Q4.6 Which CAAD program(s), if any, do you use for sketching?

Q4.7 If you don't make sketches within CAAD, please explain why not.

Section 5: **Design Medium Preferences**

Q5.1 How important is it for you to sketch on paper before starting to work with CAAD?

☐	☐	☐	☐	☐
Very unimportant	Unimportant	Neither important or unimportant	Important	Very important

Q5.2 Do you need to switch from CAAD to other medium(s)?

☐ No I don't. **Please go to section 6**

☐ Yes, I need to sketch on paper

☐ Yes, I need to make a physical model

☐ Other ,please explain

Q5.3 Do you tend to change the conceptual design when you switch between mediums?

☐ No

☐ Yes, In your opinion why does this change happen?

Q5.4 In which medium(s) do you find it easiest to develop new ideas?

- ☐ Sketching
- ☐ Physical modelling
- ☐ CAAD, do you use CAAD in one or more of the following:
  - ☐ 2D Abstract Drawings
  - ☐ 3D Abstract Drawings
  - ☐ 3D Model (with added details, materials)

Section 6: **Use of 3D Models(Physical or Digital) In The Early Stages of The Architectural Design Process**

Q6.1 How important is it for you to create a 3D model (either physical or digital) early in your design process?

☐	☐	☐	☐	☐
Very unimportant	Unimportant	Neither important or unimportant	Important	Very important

Q6.2 How often do you create 3D models of your designs with CAAD (at any stage of the design process)?

☐	☐	☐	☐
Never	Sometimes	Often	Always

If you ticked 'Never', **please go to Q 6.4.**

Q6.3 In which stage(s) of the conceptual design process do you create **3D digital** models?

- ☐ Design brief analysis
- ☐ Outline design
- ☐ Final sketch design
- ☐ None
- ☐ Other phase (s) please specify

Q6.4 Please describe how you think exploring your conceptual ideas in 3D (physical or digital) affects your work.

Q6.5 Please describe the main differences between physical modelling and digital modelling you have experienced within your architectural designs.

Section 7: **Evaluating CAAD Programs**

Q7.1 How do you rate the quality of CAAD programs in general?

☐	☐	☐	☐	☐
Poor	Fair	Good	Very good	Excellent

Q7.2 What would you most like to change about CAAD programs?

If you would like to participate in a further study on this topic, please write your name & your E-mail address:...

Many thanks for your co-operation.

B-2 Questionnaire B (2006)

CAAD at the conceptual stage of the design process

Section 1: Participant's Background Information

Matric .No	....	**Outside the school you have access to......**
Gender	☐ Female ☐ Male	☐ Personal computer ☐ Laptop ☐ Internet☐
Age	.... years	CAAD software like: ....

Section 2: Designing general skills

Q2.1 As an architect how do you rate your skills in the following:

A My skill level in architectural design is:

☐	☐	☐	☐	☐
Poor	Fair	Good	Very good	Excellent

B My skill level in sketching is:

☐	☐	☐	☐	☐
Poor	Fair	Good	Very good	Excellent

Q2.2 What is your level of experience with CAAD?

☐	☐	☐	☐	☐
Poor	Fair (*Basic 2D*)	Good (*Basic 2D & Basic 3D*)	Very good (*Detailed 2D&3D*)	Excellent (*3D Modelling & Animation)*

Q2.3 How did you obtain your CAAD experience? (*tick as many as apply*)

☐	☐	☐	☐
University Course	Private Course	Personal Effort	Architectural Practice

Q2.4 How long ago did you start learning CAAD?

☐	☐	☐	☐	☐
1-2 years ago	2-4 years ago	4-6 years ago	6-8 years ago	More than 8 years ago

Q2.5 How long ago did you start using CAAD in design?

☐	☐	☐	☐	☐
1-2 years ago	2-4 years ago	4-6 years ago	6-8 years ago	More than 8 years ago

Q2.6 Do you think learning CAAD has influenced your designing capability?

☐ Yes, I do ☐ No, I don't.

Please explain your answer...

Q2.7 Do you think acquiring CAAD skills has improved your architectural design skill?

☐ Yes, I do ☐ No, I don't.

Please explain your answer...

Q2.8 What do you think about generating conceptual design by the use of CAAD (*AutoCAD, SketchUp, etc.*)?

☐ I have never heard about that.

☐ I have been never taught that.

☐ I never thought that is possible.

☐ I think it is interesting, but I would never use it.

☐ I think it is interesting, but I need to become skilled at CAAD first.

☐ I think it is interesting, I would like to try it even though my skill level is poor.

☐ I do this already.

Q2.9 How would you describe your use of CAAD while designing?

☐ I never use CAAD [**Please answer Q5.1, Q5.6, Q6.5 ONLY**].

☐ I am aware of CAAD, but I have never used it [**Please answer Q5.1, Q5.6, Q6.5 ONLY**].

☐ I only use CAAD sometimes [**Please answer the following sections].**

☐ I use CAAD on a regular basis [**Please answer the following sections].**

Q2.10 I use CAAD in the

☐ Early phase of the design process (Design brief analysis, outline design, final sketch design).

☐ Final phase of the design process (Detail design & Development).

☐ Both phases.

Section 3: CAAD Use & Programs

Q3.1 Do you tend to use CAAD as a drafting tool or as a designing tool?

☐ Designing tool ☐ Drafting tool ☐ Both

Q3.2 Which of these CAAD programs do you use?

☐ AutoCAD ☐ 3ds Max ☐ VectorWorks

☐ Autodesk VIZ ☐ ArchiCAD ☐ Rhino 3D

☐ Autodesk Architectural Desktop ☐ SketchUp ☐ Microstation

Section 4: CAAD Use In The Early Phases Of Design

Q4.1 Would you use CAAD as the **sole medium** in any of the following conceptual design phases? (*tick as many as apply*)

☐ Design brief analysis (brief requirements) ☐ Outline design ☐ Final sketch design ☐ None

☐ Other(s), Please specify..

Q4.2 During conceptualisation, does using CAAD help you to (*tick as many as apply*)

☐ Understand my design better ☐ Identify design problems successfully
☐ Communicate my ideas to others ☐ Explore complex geometry in design
☐ Express my ideas better ☐ Think of more than one design
☐ Understand the design brief ☐ Speed up my design process
☐ Straighten up my pre-conceptual ideas ☐ Other(s), please specify

Q4.3 Please specify the ways in which you think using CAAD affects your work.

Q4.4 If you think your work with CAAD has changed the opinion you had about the role of CAAD in conceptual design, please specify why.

Q4.5 Which type of drawing (s) (sketches, diagrams, others), if any, do you use CAAD for?

Q4.6 If you don't make any conceptual drawings within CAAD (which influence your decision making process), please explain why not.

Section 5: Design Medium Preferences

Q5.1 Do you agree that the act of drawing is important to enable you to develop your ideas?

☐	☐	☐	☐	☐
Completely agree	Mostly agree	Somewhat agree/disagree	Mostly disagree	Completely disagree

Q5.2 How often do you create 2D abstract drawings of your designs within CAAD (at any stage of the design process)?

☐	☐	☐	☐
Never	Sometimes	Often	Always

Q5.3 How important is it for you to draw on paper before starting to work with CAAD?

☐	☐	☐	☐	☐
Very unimportant	Unimportant	Neither important or Unimportant	Important	Very important

Q5.4 Do you normally switch between CAAD and other medium(s)?

☐ No, I don't.

☐ Yes, I need to sketch on paper.

☐ Yes, I need to make a physical model.

☐ Other(s), please explain...

Q5.5 Exploring my design early in CAAD has (*please tick as many as apply*)

☐ Changed my opinion about early concept visualization.

☐ Changed my opinion about the use of computers in conceptual design.

☐ Changed my design.

☐ Changed my sketching tendency/frequency, (I tend to sketch ***less/ more*** now) – *please circle.*

Q5.6 In which medium(s) do you find it easiest to develop new ideas?

☐ Sketching.

☐ Physical modelling.

☐ CAAD, do you use CAAD in one or more of the following:

☐ 2D Abstract Drawings.

☐ 3D Abstract Drawings.

☐ 3D Model (with added details, materials).

Q5.7 When you are designing within CAAD, do you find yourself thinking mainly about

☐ The conceptual content of your design.

☐ The drawing appearance details and finishes.

Q5.8 When you are working within CAAD, do you spend most of the time thinking of

☐ What you are drawing on the screen

☐ How to draw it

☐ Both, what to draw and how to draw it.

☐ I don't know.

Q5.9 When I am working with CAAD I find it

☐ Hard to follow my thought sequence.

☐ Easy to follow my thought sequence.

***Section 6*: 3D Models (Physical or Digital) In The Early Phase of Design**

Q6.1 Do you experiment with your 3D concepts using any CAAD program?

☐ Yes I do, I find it interesting to see my early concepts in CAAD.

☐ Yes I do, it offers unpredicted results to my pre-concepts.

☐ Yes I do, I find it useful in developing many ideas.

☐ No, I don't like using CAAD early to experiment with my concept.

☐ No I don't, it is a waste of time.

☐ No I don't, first I would have to obtain a higher level of CAAD practice/experience.

☐ Other, please specify.

Q6.2 How often do you create 3D models of your designs with CAAD (at any stage of the design process)?

☐	☐	☐	☐
Never	Sometimes	Often	Always

Q6.3 Approximately how long do you spend on CAAD abstract modelling for a typical design project? (in Hours Or Days)

Q6.4 In which stage(s) of the conceptual design process do you create ***3D digital*** models?

☐ Design brief analysis ☐ Outline design ☐ Final sketch design ☐ None

☐ Other phase(s), please specify

Q6.5 How do you think exploring your conceptual ideas in 3D (physical or digital) affects your work?(*Tick as many as apply*)

☐ Makes it easier to imagine spaces.

☐ It is good for representing. Showing perspectives of the spaces in the building.

☐ It provides me with a more realistic approach.

☐ Helps visualisation of forms and spaces.

☐ It allows seeing things in a way I can't in 2D.

☐ It gives me a better understanding of how the ideas would function, how would it work.

☐ It helps visualisation, but can also be a time-wasting diversion.

☐ Other(s), please specify

Q6.6 Please tick the main differences between physical modelling and digital modelling you have experienced within your architectural designs.

Physical modelling is *better* for	**Digital modelling** is *better* for
☐ The sensation of light, space and touch.	☐ The sensation of light, space and touch.
☐ Speed of completion.	☐ Speed of completion.
☐ Design exploration.	☐ Design exploration.
☐ The construction process cognition.	☐ The construction process cognition.
☐ Mental stimulation.	☐ Mental stimulation.
☐ Interactivity and immersion.	☐ Interactivity and immersion.
☐ Flexibility and adaptability.	☐ Flexibility and adaptability.
☐ 3D recognition.	☐ 3D recognition.
☐ Other(s), please specify	☐ Other(s), please specify

Section 7: CAAD Teaching Methods

Q7.1 Which do you find the most useful way to learn CAAD as a designing tool?

☐ Lab Classes ☐ Tutorials ☐ Books ☐ Architectural Practice ☐ Computer

Augmented Design Studio ☐ Other(s)...................................

Q7.2 What topics would you like to see covered in a new CAAD course?

Many thanks for your co-operation & Good Luck!

Appendix C: Studio Reflection supplementary material

C-1 Semi-Structured Interviews-Set 1:

Reflection on action: an interview

2nd Point: 9th pin up Review: proposing different conceptual options

Aim: to produce a range of possible scenarios

Name:	Role:	Date:

At this stage how would you describe your work?

Have you explored any conceptual alternatives (options) for your project?

☐Yes ☐No

What is the concept that you did explore in CAD?

What is the problem that you did find and explore?

How did you explore it? By what means? Describe the **process** of your thinking/designing.

Media that you have used: media that you prefer to work with?

☐ Physical Modelling	☐ CAAD Modelling	☐ Verbal Discussion	☐Others, please specify
☐ Hand Drawings	☐ CAAD Drawing	☐ Written Description	

What other media have you tried so far? What worked? What didn't?

In what format you have worked with this media?

☐ 2D ☐ 3D ☐ Both ☐ Others:

Which program did you use? Which program do you like to use?

Why did you choose this (these) particular media? (project size, existing building, visual formation, speed)

In your opinion what was the purpose of the drawing(s) (physical, digital) you have produced?

What motivates you to use CAAD soon in presenting your conceptual options?

Does CAAD keep your thoughts flow going?

Which product , process or activity made your design work (concept) more understandable?

If you would change one thing in that presentation what would it be?

So far what do you think is the result of this stage work? (E.g. New concept; problem has been solved; what kind of problem?)

Would agree designers are using new media to find a visual formation or composition that produces something that look relatively interesting?

Do you find this statement applicable to you when you are using CAAD?

Where did you start with it?	☐ Home ☐ PC ☐ PLT	☐ Studio ☐ PC ☐ PLT	☐ Lab ☐ PC ☐ PLT
How did you start with it?	☐ 2D ☐ 3D ☐ Scanned drawing ☐ Digital drawing		

What possibilities are being explored in these drawings? (your conceptual design focus)

What has been the main influence on your work so far? ☐Tutor ☐ Design Brief ☐ Chosen Media ☐ CAAD ☐ Review ☐ Others

What do you think you have learned from creating these drawings or models?(in terms of your conceptual design options)

What have you learned out of this review?

Have you experienced anything like (presenting your options in CAAD early in the design process) this before? If so what did you do?

Do you think redraw these options by you hand would make a difference?

Have these options made you decide your direction for the next stage?

Do you think this direction was influenced by the media you have chosen?

Finally, are these questions useful for you to re-think your work?

Appendix C-2 Semi-Structured Interviews –Set 2:

Reflection on action: an interview

2nd Point: 9th pin up Review: proposing different conceptual options

Aim: to produce a range of possible scenarios

Name:	Role:	Date:

At this stage how would you describe your work?
Have you explored any conceptual alternatives (options) for your project? ☐Yes ☐No
What is the concept that you did explore in CAD?

What is the problem that you did find and explore?
How did you explore it? By what means? Describe the **process** of your thinking/designing.
Media that you have used: media that you prefer to work with?

☐ Physical Modelling	☐ CAAD Modelling	☐ Verbal Discussion	☐Others, please specify
☐ Hand Drawings	☐ CAAD Drawing	☐ Written Description	

What other media have you tried so far? What worked? What didn't?
In what format you have worked with this media?
☐ 2D ☐ 3D ☐ Both ☐ Others: Which program did you use? Which program do you like to use?
Why did you choose this (these) particular media? (project size, existing building, visual formation, speed)
In your opinion what was the purpose of the drawing(s) (physical, digital) you have produced?
What motivates you to use CAAD soon in presenting your conceptual options?

Does CAAD keep your thoughts flow going?

Which product , process or activity made your design work (concept) more understandable?

If you would change one thing in that presentation what would it be?

So far what do you think is the result of this stage work? (E.g. New concept; problem has been solved; what kind of problem?)

Would agree designers are using new media to find a visual formation or composition that produces something that look relatively interesting?

Do you find this statement applicable to you when you are using CAAD?

Where did you start with it?	☐ Home ☐ PC ☐ PLT	☐ Studio ☐ PC ☐ PLT	☐ Lab ☐ PC ☐ PLT
How did you start with it?	☐ 2D ☐ 3D ☐ Scanned drawing ☐ Digital drawing		

What possibilities are being explored in these drawings? (your conceptual design focus)

What has been the main influence on your work so far?	☐Tutor ☐ Design Brief ☐ Chosen Media ☐ CAAD ☐ Review ☐ Others

What do you think you have learned from creating these drawings or models?(in terms of your conceptual design options)

What have you learned out of this review?

Have you experienced anything like (presenting your options in CAAD early in the design process) this before? If so what did you do?

Do you think redraw these options by you hand would make a difference?

Have these options made you decide your direction for the next stage?
Do you think this direction was influenced by the media you have chosen?
Finally, are these questions useful for you to re-think your work?

C-3 Post interviews questionnaire-set 3:

Final Phase Questionnaire

Student ID		**Student project**	

Section 1: Since you started this project you may have used various representational-media (*3D computer generated models, scanned in hand sketches, photography etc.*) to develop your final conceptual scenarios. We would like you to think back through your project and answer the following questions:

1. Would you please define the design task (***Old town, Aberdeen airport, Pitmadden, Tornagrain and Gray's***) in respect to *your* design aim(s) and objectives?

2. Please arrange the type of media you have used through the 1st semester project in succession. (e.g. drawing then modelling then sculpture, etc)

3. For each of the media you listed in Q2, what do you feel are the advantages?

4. Of the media you listed in Q2, which did you use more frequently during the first semester project? Please explain why.

5. If CAAD was one of the media you listed in Q2, please describe what methods you used to create your design compositions (*what kind of working methods and techniques you did apply by each program i.e. photomontage by Photoshop*).

6. Was the choice of media you have used influenced by the following(*please tick as many as apply*)

☐ The studio tutors (*i.e. encouraged by the tutor(s) to use one or more type of media)*
☐ Personal skills
☐ The type of the study undertaken (*design task characteristics*)
☐ The systematic evaluation of your study (*MArch studio teaching methods*)
☐ Your own approach to study various architectural themes
☐ Project characteristics (*i.e. complexity, size, surroundings, others)*
☐ Accessibility and affordability
☐ Others, ***please specify***

7. If you had not been able to use CAAD during the project, do you think that would have affected your design process? If yes, please explain why.

8. Was using ***a variety of media*** useful to you in (*tick as many as apply*)
☐ Speeding up the systematic evaluation of your study
☐ Collaborating with other students
☐ Looking at more than one conceptual possibility of the project
☐ Looking at more than one conceptual aspect of the project
☐ Overcoming the design task uncertainty (*ambiguity*)
☐ Prompting design creativity
☐ Finding an interesting visual formation that could inspire your thoughts
☐ Others, ***please specify***

9. Do you consider CAAD (visualization) as a media that help you *develop* new ideas?
☐Yes ☐No

Please explain your answer

10. Did using CAAD force you to think about a specific aspect(s) of the design project? If so, what were these design aspects?

11. While developing a design, what motivates you to change the media you are working with?

Section 2: *CAAD Experience*

1. Has *your CAAD experience* influenced one or more of the following design tasks (*please tick the most applicable to your design process*)

☐ The way you document solutions
☐ The way you make decisions
☐ The way you communicate design
☐ The way you think about design
☐ The way you solve design problems

2. If you have not ticked any boxes in the previous question, why do you think this might be?

3. Do you feel that your design ideas change when you start using CAAD as a design medium? Please explain why?

Section 3: *The Final Presentation*

1. What were you trying to convey through your final presentation?

2. How important was the final presentation for the development of your potential scenarios?

3. If you could change one thing in your presentation, what would it be?

Section 4: *The Design Methodology*

1. One of the requirements was to produce various 3D wooden physical models. Do you feel it would be useful to mix these with 3D digital models?

2. Did you apply any familiar design techniques in new ways? Please explain how?

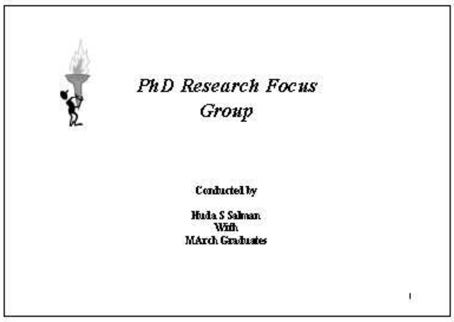
3. Did you learn new CAAD techniques or design techniques during the project? Please explain how?

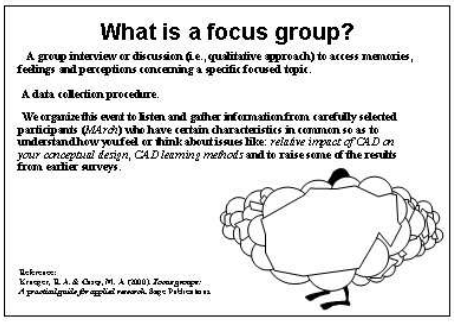
Many thanks for your participation.

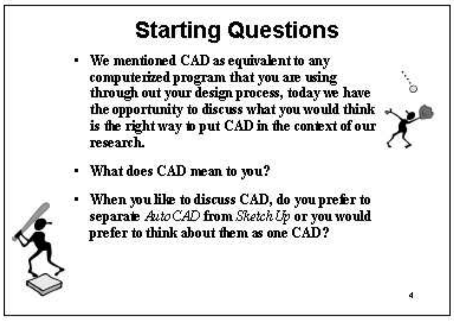
Appendix C-4 The focus group guide

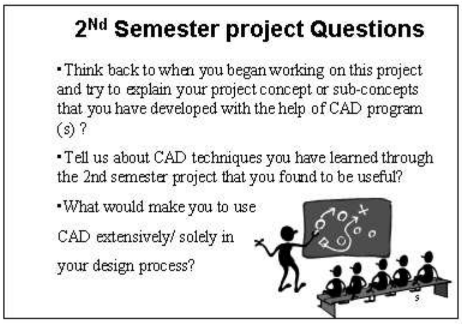
The used template for the guide was based on *Focus Group Workshop* presentation by Thomas E. Grayson, can be retrieved from:

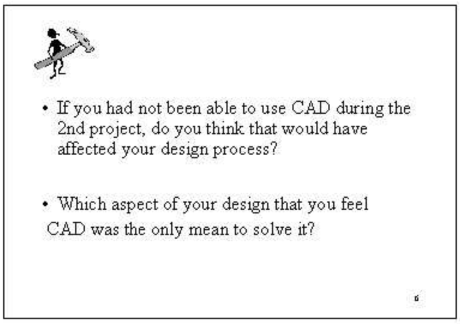
www.real-timeupdates.com/it/uploads/ppt/22787.ppt

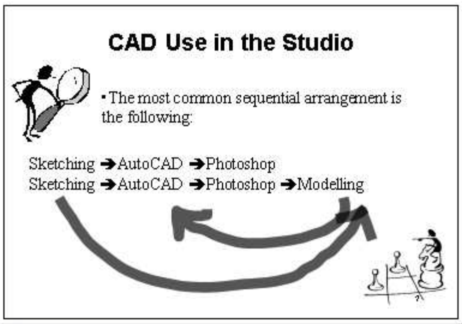


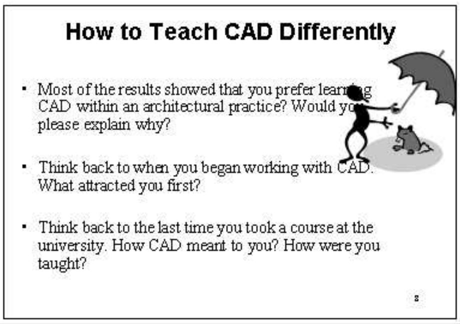












Precedents and Design Methods

- Are you interested in knowing other architects design methods?
- Do you think that other architect's methods are useful for your design process? Like Lynn and Gerry.
- When you select relative precedents, what criteria do you use for determining this?
- How do your criteria evolve through the design process?

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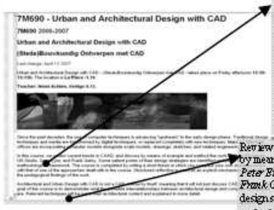
Eindhoven University of Technology Design Systems Course



Architectural and Urban Design with CAD is not a CAD course by itself, meaning that it will not just discuss CAD techniques. The goal of the course is to demonstrate what the possible interrelationships between architectural design and computer techniques are. Relevant techniques will be put in their architectural context and explained in more detail.

Review current trends in CAAD, and discuss by means of example and method the work of *Peter Eisenman*, *UN Studio*, *Greg Lynn*, and *Frank Gehry*. Some salient points of their design strategies are identified and put in a methodological framework.

http://www.ds.arch.tue.nl/7m690/

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Task 1: Choose your architect

	Eisenman	van Berkel	
Architectural concepts	• Artificial excavation • tracing • layering • palimpsest • diagrammatic image	• Deep plan • public construction • movement patterns • diagram • continuity • hybrid	• Force • movement • dynamic space • animation
Formal techniques	• Shear • interference • intersection • distortion • superposition • scaling • rotation	• Topology • surfaces • continuity • movement analysis	• Multi-type of performance envelope • topology • time • multiplicities • curvature • blobs, flowers, strands, sheds, lattices
CAD techniques	• Terrain • free form deformation • bend, push, shell, boolean • mesh editing	• Patch • nurbs surfaces • dependent surfaces: ruled, 1-rail, 2-rail, u loft, uv loft	• Spline • nurbs surface • animation • keyframing • blobowshes • 1-rail, u loft, loft, lattice

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Task 2: Analysis

- In this task you will look at the analysis techniques used by the architect that you have chosen.
- If you want to work with Eisenman's method, then you have to make a historical map analysis by means of tracing.
- If you want to work with UN Studio's method, then you have to analyze the site in terms of actual and desired movement patterns.
- If you want to work with Lynn's method, then you have to analyze the site in terms of movement and forces.

12

Ending Questions

- What do you think is the most important part of this discussion?
- If you are the researcher, what would be the next question you would ask the group?
- Have we missed anything?

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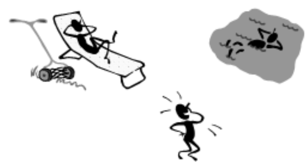
Have a nice Holiday



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Appendix D the protocol study methods

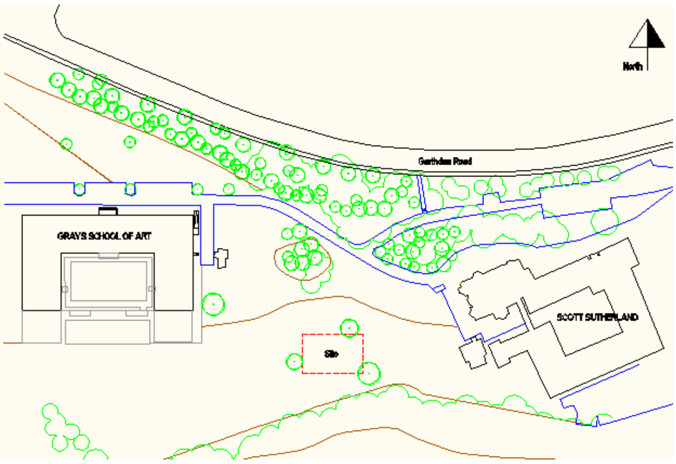
D-1 Design brief (task)

Art & Architecture Gathering Space

Client:
Your task is to design a gathering forum for the students, staff and guests of the Scott-Gray's schools on the Garthdee campus.
The designing task involves the creation of an effective gathering space which would unite the Garthdee campus students, staff and guests in an inspirational environment of art and architecture.

Site:

In a sensitive site that relays in-between the Scott Sutherland School and Gray's School of Art enjoying the contact with the natural environment of the river Dee and the grand tree line along the southeast edge with a sloping ground towards the river edge. Site dimensions are as shown in figure 1-1.



The site

Gathering space:

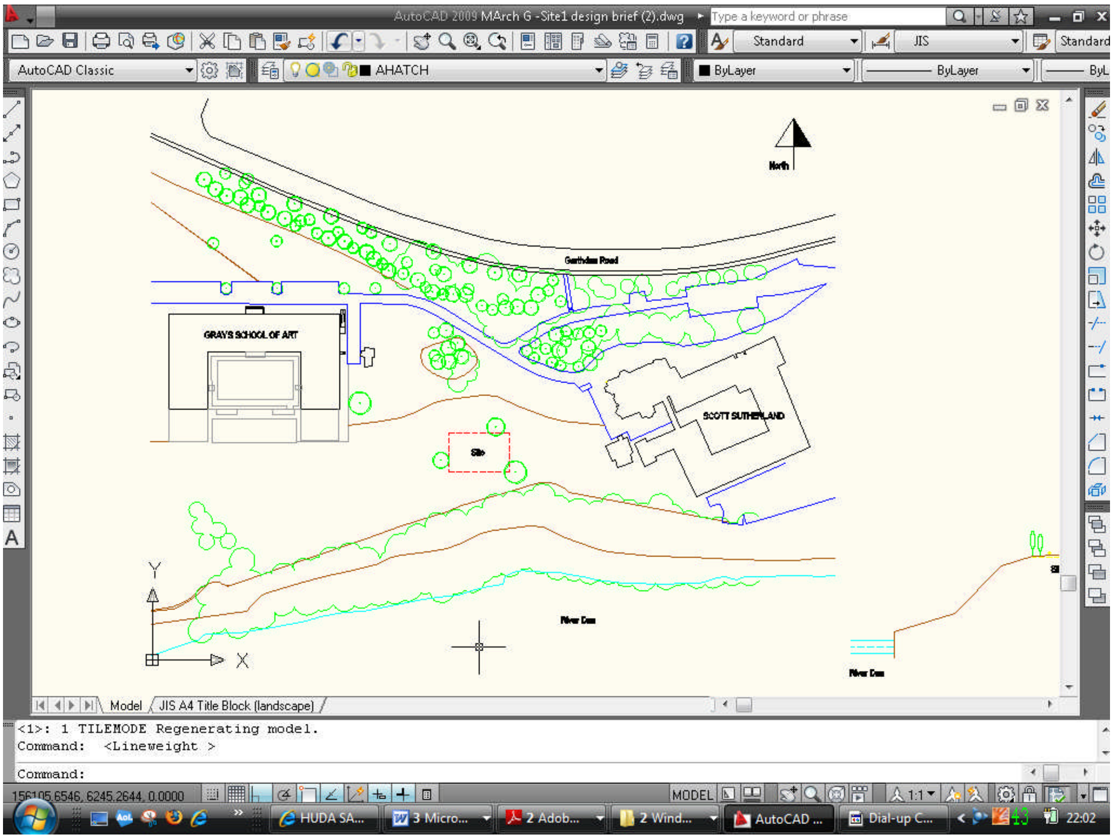
This space is expected to be embraced by the river Dee flow, and screened by a grand line of magnificent trees along one edge of the site. A sculpture garden is required for display of the students' art collections, an architectural display area for physical models and electronic images or slides. At the same time it is a relaxing area where students and staff can find lunch meals and hot/cold drinks.
So initially the designed space has to accommodate the following activities; seating, eating, relaxing and visualising artistic subjects.

Your task is to give forms to and arrange the following spaces on the site with the approximate sizes:

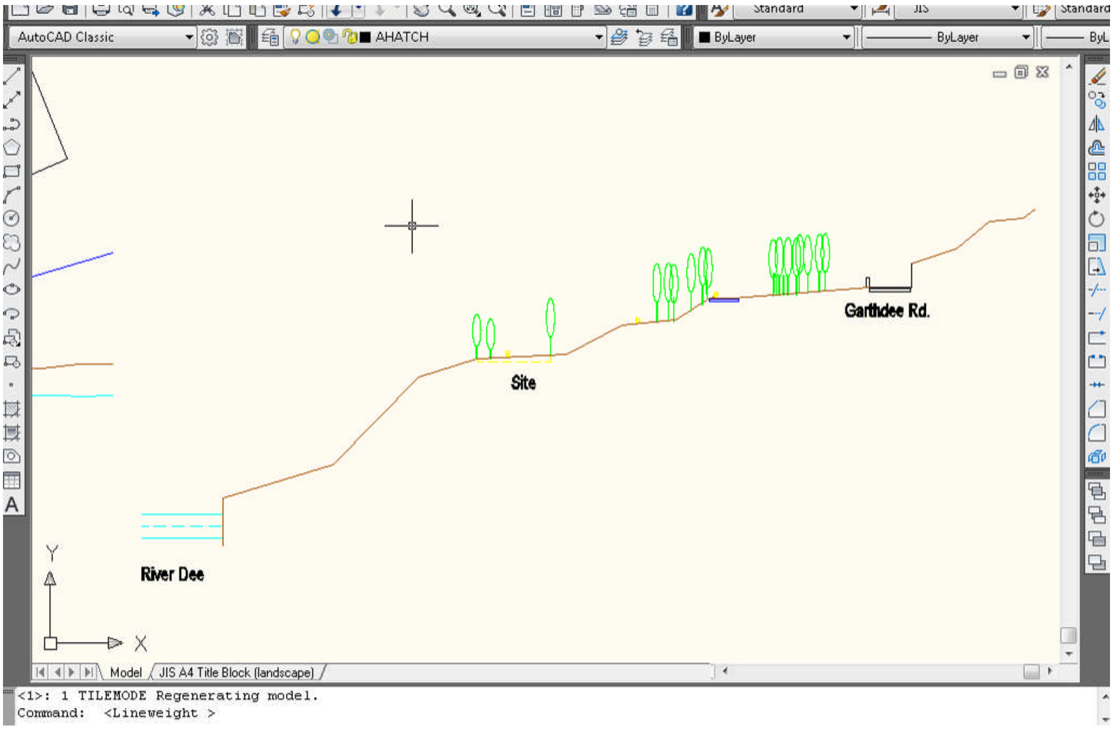
Dining area A,B,C:	**50 m^2 x 3**	***Seating area***	**15 m^2**
Display area:	**20 m^2**	***Sculpture garden:***	**30 m^2**
Kitchen:	**15 m^2**	***Serving area:***	**20 m^2**
		Wc	**10 m^2 x 2**
In a total area of 320 m^2			

Site Images

D2 Brief CAAD Drawings



The site CAAD drawing



The site section CAAD drawing

Appendix D3 Coding schemes

Gero and Mc Neill (1998 p22-23) asserted, "*A framework can be brought to the design process by considering the designer's activity as consisting of a sequence of actions or micro strategies each typically lasting for a few seconds or tens of seconds. The design process can be viewed as one in which the designer engages the design problem by calling upon a repertoire of micro strategies.*"

Table: Micro strategies used in the Gero & McNeill (1998) design episodes

	Analysing Problem	Relate to actions involving analysis of problem.
Ap	*Analysing the Problem*	Indicates that the designer is analysing, qualitatively or quantitatively, a design problem. This may be in the form of calculations or as a run through of expected behaviour [Functional aspect of users or the artefact?]
Cp	*Consulting Information about the Problem*	As above but using external information[as a n example he mentions the brief as an External information]
Ep	*Evaluating the Problem*	That is an important feature, strong constraint
Pp	*Postponing Analysis of the Problem*	Relating the current status with the latter or a future one. I can find that latter.
	Proposing Solution	refer to the proposal of a solution or partial solution.
Ps	*Proposing a Solution*	is self explanatory[refer to the proposal of a solution or partial solution.]
Cl	*Clarifying a Solution*	indicates that the designer is repeating a previously proposed structure and perhaps elaborating the details of the structure.
Re	*Retracting a Previous Solution (D Dc)*	means that the designer has rejected a whole proposed solution as opposed to modifying a solution by varying parts of it.
Dd	*Making a Design Decision*	comes at the end of a period of considering alternatives. It is characterised by a decision without further elaboration of the proposed structure.
Co	*Consulting External Information for ideas*	is used to denote that the designer is consulting other information to look for options for the solution It is not used when the designer is analysing some aspect of the external information to gain a greater understanding of a structure's behaviour.
Pp	*Postponing a Design Action*	indicates that a need for some structure has been identified but its elaboration has been postponed in favour of another, perhaps easier, task
La	*Looking Ahead*	it means the designer is identifying some future structure that will be required
Lb	*Looking Back*	Modifying a solution by varying parts of it
	Analysing Solution	relate to actions involving analysis of some behaviour.
An	*Analysing a Proposed Solution*	indicates that the designer is analysing, qualitatively or quantitatively, a solution idea. This may be in the form of calculations or as a run through of expected behaviour.
Ju	*Justifying a Proposed Solution*	does not involve calculations or a run through but the designer makes some comment that indicates that some assessment of the behaviour of a proposed solution has been made.
Ca	*Calculating on a Proposed Solution*	
Pa	*Postponing an Analysis Action*	
Ev	*Evaluating a Proposed Solution*	differs from the other categories in that it involves

		some type of value judgement of the proposed solution.
	Explicit Strategies	*to indicate that the designer is explicitly referring to something. These correspond to times when the designer is not directly engaging the design task.*
Ka	*Referring to Application Knowledge*	*refers to knowledge of the application or environment in which the artefact is to be used.*
Kd	*Referring to Domain Knowledge*	*refers to knowledge of the domain of the design,*
Ds	*Referring to Design Strategy*	*identifies when the designer is commenting on the progress of the design episode or is assessing his own design strategies.*

Level of abstraction codes (1,2,3) was used in Gero & McNeill's (1998) design episodes and Purcell, Gero, Edwards, and McNeill (1996)

Level 0	0 is used to denote the top level of abstraction where the designer is considering the problem as a whole
Levels 1,2,3	is used to refer to the sub-problems identified by the designer.
Level 4	Was used in this study to denote the detail level of abstraction, where the designer is considering a technical problem

Keyword Group: External representations. This has been developed using Transana platform

External representation coding scheme [6/08/2008 updated version]

ChVw A	Changing the view into another drawing or design entity. or be defined upon the continues nature of using CAD commands
ChVw S	Changing the view in the same drawing or design entity in out=inspect global relations out in =inspect local relations
Copy G.	Copy a given diagram or design entity into other location in the aim to start new modifications- Equivalent to starting with a new sheet
Crt A	Create by adding a new design element or entity to a former design entity after a time gap (relating two different segments).
Crt C	Continue drawing on the same part(s) or design entity in successive segments. no conceptual gap same segment or related elaboration
Crt G	Group created elements; it is either by creating adjacent entities or by duplicating (copy) an object (or drawn object) in one segment duration.
Crt N	Create by drawing a new design element or entity, or inserting an object into the environment.
Discv R	Discovering a relation: an organizational relation between two spaces unintentionally, resulted from inspecting new relations by moving objects or design elements
Discv S	Discovering a space as ground unintentionally, resulted from the appearance of other surroundings.
Insp G	Make calculations and reading information (height, width, diameter, etc,) off

Insp P	Make calculations and reading information (height, width, diameter, etc,) off his drawn entities. It is either inspect or observe!
Mod D.	Erase or delete a design element or a design entity results in modifying the design composition
Mod G.	Modifying a composition by moving previously created objects or entities
Mod M	Move element or entities around the objects after they are created. This is to align them, or to carry them for using in another location.
Mod VA	Orientate/Rotate/change their arrangements, resizing or changing the shape. Changing its visual attributes: shape, angles and sizes
Pres	Applying hatch or colour and texture.
Ref G	Looking at the Given representation and refer to its parts (object or entity) using hand gesture over the screen or the mouse curser (referring to a representational part or design aspect
Ref N	Looking at the new representation and refer to its parts (object or entity) using hand gesture over the screen or the mouse curser (referring to a representational part or design aspect)
Text	Labelling spaces
Zo IO	zooming in & out: inspecting global relations
Zo OI	Zooming out & in: inspecting local relations

Appendix E Survey Result Tables (SPSS)

		the act of drawing is important to enable you to develop your ideas	How often do you create 2D abstract drawings	How important is it for you to draw on paper before
N	Valid	50	50	50
	Missing	0	0	0
Median		1.0000	2.0000	5.0000
Mode		1.00	2.00	5.00
Skewness		1.159	.609	-2.027
Std. Error of Skewness		.337	.337	.337
Kurtosis		.156	.143	3.165
Std. Error of Kurtosis		.662	.662	.662
Range		3.00	3.00	4.00

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	What you are drawing on the screen	17	34.0	35.4	35.4
	How to draw it	2	4.0	4.2	39.6
	Both, what to draw and how to draw it.	26	52.0	54.2	93.8
	I don't know.	3	6.0	6.3	100.0
	Total	48	96.0	100.0	
Missing	System	2	4.0		
Total		50	100.0		

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Harder to follow my thought sequence	12	24.0	24.5	24.5
	Easy to follow my thought sequence.	37	74.0	75.5	100.0
	Total	49	98.0	100.0	
Missing	System	1	2.0		
Total		50	100.0		

Appendix F Studio reflection analysis: Point one of reflection

On the other hand, the booklets were useful *“I thought it was good when we all put our work together that you could see, producing the booklet especially, you could see what we have done.”* (Sa3).

Whether the produced artefacts (model, drawing) would affect the student design conceptually, the student (Sa3) separated what is analytical from what is regarded as a complementary act (drawing activity).

> ”*The drawings, well no not creating the drawings but doing the analytical stuff, you know, learning from it : yes, but not the way I drew it, because it was just a case study. So no.”* (Sa3).

In other words, it is not my design. May be drawing is related with authorship and identity but we said that drawing brings understanding as well, from understanding we can develop themes to be used in the next stage.

Project model

Another aspect of the studied precedent had been recognised in this extract, which is “*typography*” of the town and its conceptual relation with town planning and development. Based on this aspect, sequence was taken as a conceptual theme informing next stage work by suggesting an appositive theme to what has been identified “…. *starting in the centre and working out in all direction.*” Also “*try to find a suitable place for the centre that expands in all directions.*” And”. *so trying to pick a sort of suitable location within the site that isn't going to constrain outward development*”,

> *“..to expand from a sort of single point out the way and in whatever direction they can rather than starting in the centre and working out in all directions. .. that would be one thing, you know, I would take to the next project to try and find a suitable place for the centre that, you know, to kind of like expand in all directions and, you know, allow developments all around the centre rather than up one side of the centre or whatever”*
>
> *“So trying to pick a sort of suitable location within the site that isn't going to constrain outward development.”*
>
> *“so I think that would be another thing that I would take, yeah.”*

Student (Sa2) was more specific in identifying what is expected from them as a group. In this extract, the student has described the way in which they analysed the given precedents and how they approached the conceptual themes of town planning.

> *"May be the urban scale, because we have not really done anything on a big urban scale before. I mean we have looked at Stonehaven and we looked at how it works, in the second year and but we have looked at how it works, but we have not compared town layout and I think just the scale." Sa4.*

While student (Sa 4) was successful in knowing and focusing on one new aspect was learned as a result of the studio work and that was the "urban scale". So this student learning process has one emergent them which is scale. [This must reflect that the process they have been through was useful towards this understanding whether the models or the drawings they have produced].

Effect

Through precedents analysis, the interviewee mentioned that making a model for the precedent was useful to corroborate other 3D aspects of town layout, quoting the student " *it showed things like density*", " *and types of building*". As a result, the model "…*gave a good idea of layout without having to develop a map*..." (S a2)

This extracts provide another example on media process recognition. Related to the point where I said that familiarity of the process is there but it might be unconscious. However, this example provides a conscious evaluation of the making of the physical model for the new site.

Various media, understanding, scale, recognition

Studying the precedent actively, i.e. by exploring it using various media, has affected the students' understanding and scale recognition of the case study. This made them recognise the difference [related both] between how it (case study) looks and the precedent actual size (scale). Quoting the student Sa1

> "*Stonehaven [case study] does not seem like that big a place but when you are actually trying to separate everything into groups and zones everything, it is a lot bigger than it looks*".

The variety of mediums that were used in studying and analysing the precedent to understand the scale [actual size] of the precedent [town] beside the practicality of this process were influential in changing the student's preconceptions. Thus, precedent(s) study has another role in confirming and confronting the student's preconceptions in terms of the design case and the underlying design (planning in this case) theoretical issues and principles.

Many themes were related to the fact that the drawings techniques were used (zoning, coding, highlighting) as means for maturing the students' understanding of the given precedent (new town experience and conveying its character).

Site visit (case study) was identified (by Sa2) as the most effective practice at this stage, then making the model to learn a lot about the town. This refers to how a student constructs a feeling and experience of a new place they are studying. We think that this is also related to what makes them produce a film, beside other things -means- this group tried to convey their feeling about the new town (precedent) through filming [strategic filming /sequenced documentation of the town]. I think that this expression was learned and decided as a result of their site visit and modelling work or the planning work behind model production.

Summarising what has been learned as a result of this stage work, the students have identified things (themes, ideas) that they were going to build on conceptually in the next stage of their studio project. Things were identified by the student (Sa2) consisted of the following:

> "*I suppose it has given us a few examples …and it has given us things to think about in that issues like how a town actually works, about people who are going to want to drive in or if it is too, too far away and where they park, it makes me think about things like that I suppose practical issues of a town*."(S2).

Moreover, this stage work relation to the next stage, as this stage understanding has helped in narrowing down their focus to issues they found and would want to embrace within the next stage. As student (S4) mentioned that "*I think it has focused our thoughts on how the town centres, what goes into them, what makes [it work], what sort of materials we need to think about, what sort of style of buildings to do up to the next stage where we design or plan*."

The result of this stage work?

"Erm (pause)shown us two very different towns which as … well, local towns, which we can either take the best bits from, for instance the, the squares and in … well the square in Stonehaven and the crossing and] …and it's also shown us the worst parts and what, you know, what, what a development can do to a town, you know, big housing development can kind of suck the life out of a town, so I

think that's, that's helped us in -a certain ways." Sa3.

Considering the advantages of the precedent planning along the disadvantages and creates thematic interests to convey as conceptual elements for the next stage of the design project.

"I suppose it's given us a few examples …and it's given us things to think about in that issues like how a town actually works, about people who are going to want to drive in or if it's too, too far away and where they park, it makes me think about things like that I suppose practical issues of a town."Sa2.

This extract shows that the student (Sa1) has learned many aspects of town planning, themes that he would take on to the next phase of the project. Such as, use integration, and he has suggested multiuse zones for the new town as a result of drawings.

"I think the problems are, <u>well we have realised what we need to look at in part</u>, but there is still so much to look at. And you never realise the whole problem. By the end, you know, you have done a one year design scheme and you still … there are still things you don't know about" (Sa2).

Have these options made you decide what direction for the next stage?

Sa1 I think they have … I think Stonehaven shows the … maybe not the worst way but not … definitely not the best way of designing a town and growing a town as well (pause) ah yeah, I'd definitely say it wasn't the.. the worst way to design a town but at the same time it's not ideal so I think that's probably what I'd take, take out of it most, you know.

Sa3 not really because I haven't actually decided it, it might have an influence thinking about the public space and private space and working on the model may be have to -show....- buildings and places behind them, that was actually more interesting part of the building what's behind the main façade that people don't see

We can feel that the student has changed her focus of attention when we asked about the next stage work, what she is going to work on. She moved to other themes like (more focused themes) thinking about the public space and private space. This also related to her modelling work as she noticed one theme belongs to void and solid...she says that the spaces behind the building are the most interesting, behind the facade, that people do not see.

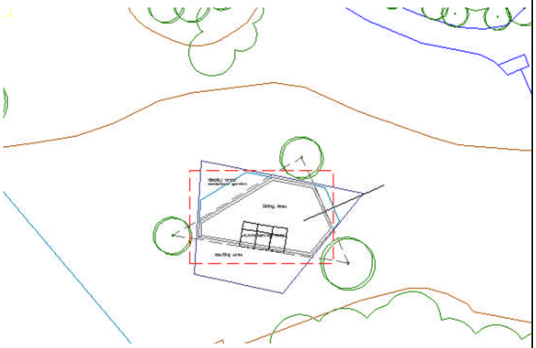
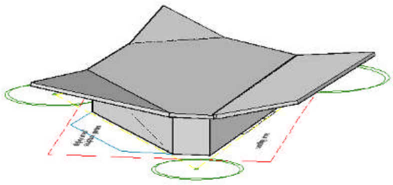
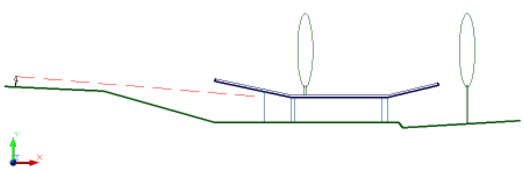
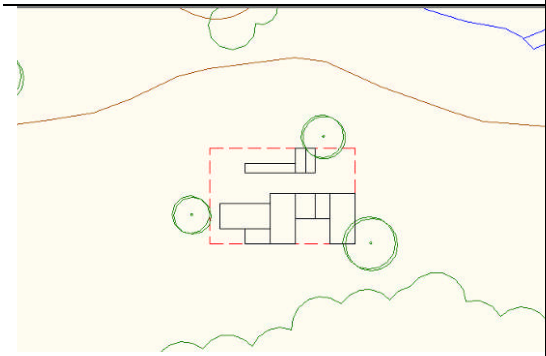
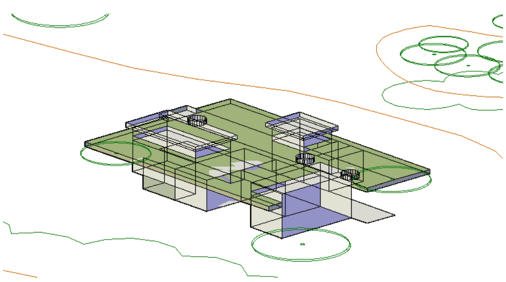
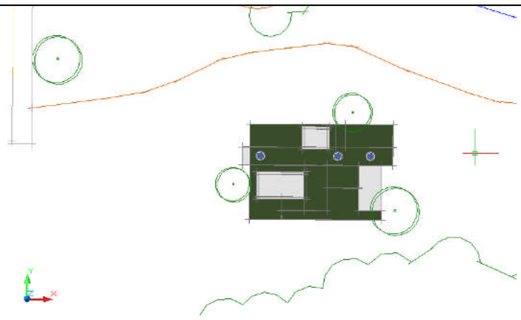
"no not exactly because we are not building up either one of these two sites

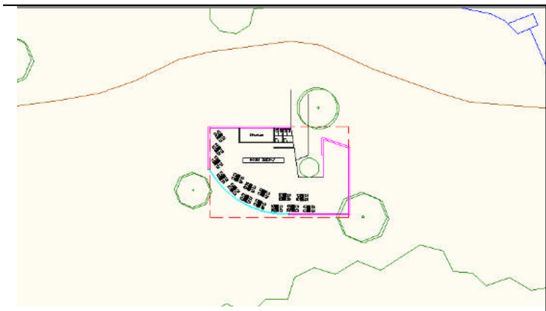
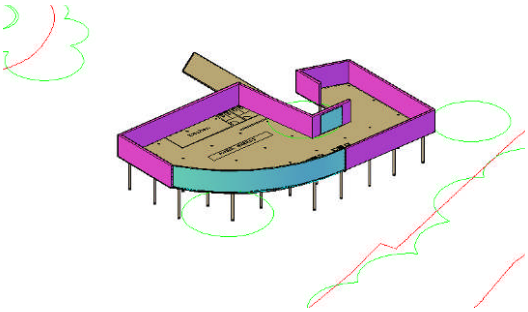
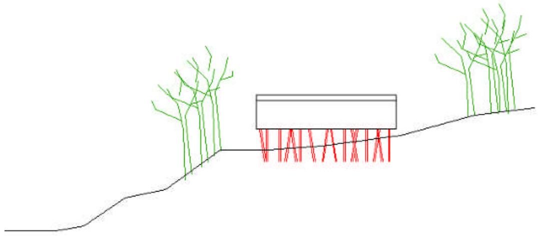
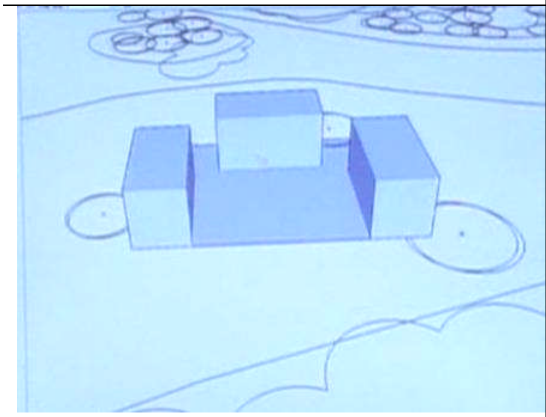
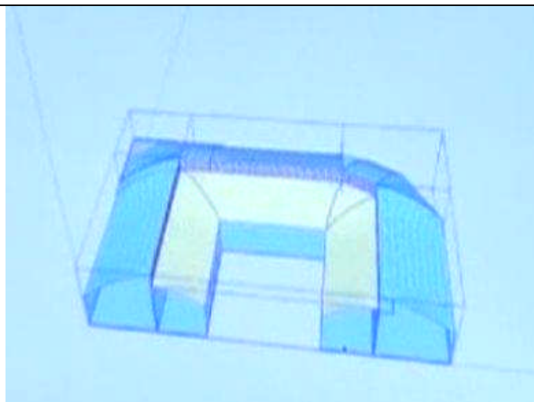
to study, so we are building up Torngrain site but of which we might need to investigate." (Sb4)

Constant with the former extracts discussed above, this extract has a relation with designing as a situated act as it has to be in context rather than non-context.

Appendix G Protocol Study Supplementary Material

Appendix G1 Participating students final representations

 SA1_ 2D-AutoCAD  AutoCAD -3D	 SA1_ 2D-AutoCAD
 SA2_ 2D-AutoCAD  SA2_ 3D-SketchUp	 SA2_ 2D-SketchUp

 ST3_ 2D-AutoCAD  ST3_ 3D- AutoCAD	 ST3_ 2D-AutoCAD
 ST4_ 3D-SketchUp  ST4_ 3D-SketchUp	 ST4_ 3D-SketchUp

Appendix G2: Transana Report for SA1

Transana Episode Report

Episode: SA1 Design

Clip: RD Seg 1

Collection: Design Process > MArch > RD-design process
Time: 0:00:00.0 - 0:00:21.3 (**Length:** 0:00:21.3)
Episode Transcript: richard2
Clip Transcript:
The immediate surroundings to the site are (*(zooming out and zooming in))* **huge multiple trees over there and I think they are quite** *((zooming-in at the site section))*.. **special within that area and people appreciate their..sun**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw A
External representations : ChVw S
External representations : Verb_Idea
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : AP_Evaluating the Problem

Clip: RD Seg 2

Collection: Design Process > MArch > RD-design process
Time: 0:00:21.3 - 0:00:56.3 (**Length:** 0:00:35.1)
Episode Transcript: richard2
Clip Transcript:
= First thoughts not *((zooming out and in to the site))***to affect those either with foundations or choice materials and...***((zooming out))*¤<35992>(0:00:36.0)**I would say the building in this site** *((looking at the whole site: site section, site plan))* **is as almost removable or not permanent or not to look permanent***((zooming in to the site section))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw S
External representations : Zo OI
Gero & Mc Neill : AP_Analysing the Problem
Level of Abstraction : 0-Whole Site

Clip: RD Seg 3

Collection: Design Process > MArch > RD-design process
Time: 0:00:56.3 - 0:01:20.3 (**Length:** 0:00:23.9)
Episode Transcript: richard2
Clip Transcript:
((zoom in and out to level -1 then to level 0))¤<61812>(0:01:01.8)*((copy the whole site once)).*

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Cpy G
External representations : Zo IO
Gero & Mc Neill : AP_Analysing the Problem
Gero & Mc Neill : Ex_Practically Working on CAD
Level of Abstraction : 0-Whole Site

Clip: RD Seg 3-4
Collection: Design Process > MArch > RD-design process
Time: 0:01:20.3 - 0:01:44.2 (**Length:** 0:00:23.9)
Episode Transcript: richard2
Clip Transcript:
The trees may also act as..aa.. Sign us to how the building could be shaped rather than the square site *((pointing at the square site))((zooming out to level1))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw S
External representations : Ref G
External representations : Verb_Idea
Gero & Mc Neill : PS_Proposing a Solution
Level of Abstraction : 0-Whole Site

Clip: RD Seg4
Collection: Design Process > MArch > RD-design process
Time: 0:01:44.2 - 0:02:38.2 (**Length:** 0:00:54.0)
Episode Transcript: richard2
Clip Transcript:
There is also the relationship to the house..The old house at the SS school that the trees have*((pointing at both trees)***) between the trees there is almost this in face that addresses the house**

¤<125715>*((Draw L1: Draw line 1 between the 2 trees (c1 and c2); draw line 2 from line 1 to the c3))*¤<142625>(*(Draw L2)*)

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt N
External representations : Insp G
External representations : Ref G
External representations : Verb_Idea
Gero & Mc Neill : PS_Proposing a Solution
Level of Abstraction : 0-Whole Site

Clip: RD Seg5
Collection: Design Process > MArch > RD-design process
Time: 0:02:38.2 - 0:02:58.8 (**Length:** 0:00:20.6)
Episode Transcript: richard2
Clip Transcript:
So this might inspire how or what relationships the building would have to each building the trees almost do that on their own

¤<171248>*((Draw L3))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw S
External representations : Crt C
External representations : Crt N
External representations : Ref G
Gero & Mc Neill : PS_Proposing a Solution
Level of Abstraction : 0-Whole Site

Clip: RD Seg6
Collection: Design Process > MArch > RD-design process

Time: 0:02:58.8 - 0:03:16.3 (**Length:** 0:00:17.5)
Episode Transcript: richard2
Clip Transcript:
*((pointing at the angle and the two buildings))***This angle might perhaps create a draw from each of the schools Gray's and SS**
((zooming from Level 0 to level1))

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw S
External representations : Ref G
External representations : Ref N
External representations : Zo OI
Gero & Mc Neill : AS_Analysing a proposed Solution
Level of Abstraction : 0-Whole Site

Clip: RD Seg7
Collection: Design Process > MArch > RD-design process
Time: 0:03:16.3 - 0:03:26.9 (**Length:** 0:00:10.6)
Episode Transcript: richard2
Clip Transcript:
Should probably at the same time be sizing the different areas what to put in this building within the structure

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw S
External representations : Zo OI
Gero & Mc Neill : AP_Analysing the Problem
Level of Abstraction : 1-Design task

Clip: RD Seg8
Collection: Design Process > MArch > RD-design process
Time: 0:03:26.9 - 0:03:58.4 (**Length:** 0:00:31.5)
Episode Transcript: richard2
Clip Transcript:
((measuring: Use the curser to measure the site from the right angle of the rectangle to the opposite side :driving information))

¤<214436>((*drawing squared space)) DS1 :* **So first can size the large spaces and the dining spaces***((copy DS2 and DS3))*

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt C
External representations : Crt G
External representations : Crt N
External representations : Insp G
Gero & Mc Neill : AP_Consulting Information about the Problem
Level of Abstraction : 1-Design task

Clip: RD Seg9
Collection: Design Process > MArch > RD-design process
Time: 0:03:58.4 - 0:04:26.2 (**Length:** 0:00:27.8)
Episode Transcript: richard2

Clip Transcript:
How many of them we need or require mmm perhaps either could be arranged *((Draw S4))* **around one another** ((zooming out and in))

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
Episods : Spatial layout
External representations : ChVw S
External representations : Crt C
External representations : Crt N
External representations : Ref N
Gero & Mc Neill : AP_Consulting Information about the Problem
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg10
Collection: Design Process > MArch > RD-design process
Time: 0:04:26.2 - 0:04:43.5 (**Length:** 0:00:17.3)
Episode Transcript: richard2
Clip Transcript:
It is also the thought of hiding service area, it's all aspects would be seen or we want to be viewed out to the south and the building would be seen from the north east and North West
((pointing at south side of the building and NE,NW))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Ref G
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Proposing a Solution
Level of Abstraction : 1-Design task

Clip: RD Seg11
Collection: Design Process > MArch > RD-design process
Time: 0:04:43.5 - 0:05:08.0 (**Length:** 0:00:24.4)
Episode Transcript: richard2
Clip Transcript:
so probably trying locate a.. *((Draw L4))****locate the service*** **areas like kitchen and toilets in-within a central hub kind of space**
((pointing at the centre of the triangular shape:sh1))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw S
External representations : Crt N
External representations : Ref N
Gero & Mc Neill : PS_Clarifying a P Solution_Details
Level of Abstraction : 1-Design task

Clip: RD Seg12
Collection: Design Process > MArch > RD-design process
Time: 0:05:08.0 - 0:05:47.2 (**Length:** 0:00:39.2)
Episode Transcript: richard2
Clip Transcript:
its got the sizes mmmm *((drawing Ks,Ts*2))*It kind of approximate sizes

((Rotate Ks And move it to Ts2))

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Crt G
  External representations : Crt N
  External representations : Mod M
  Gero & Mc Neill : PS_Clarifying a P Solution_Details
  Level of Abstraction : 2-Sub-Relations

Clip: RD Seg13
Collection: Design Process > MArch > RD-design process
Time: 0:05:47.2 - 0:06:21.3 (**Length:** 0:00:34.1)
Episode Transcript: richard2
Clip Transcript:
And see perhaps they might fit together in some sort of way *((moving it to the centre of the triangular and rotate it))*
Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Mod M
  External representations : Mod VA
  External representations : Zo IO
  External representations : Zo OI
  Gero & Mc Neill : PS_Proposing a Solution
  Level of Abstraction : 2-Sub-Relations

Clip: RD Seg14
Collection: Design Process > MArch > RD-design process
Time: 0:06:21.3 - 0:06:41.3 (**Length:** 0:00:20.0)
Episode Transcript: richard2
Clip Transcript:
Perhaps they could twist *((move it near the southern edge then on the edge))***may be to form a separation between** *((pointing at the southern part))* **southern part of the building or** *((move it back to the prev. location))***perhaps they just sit within.**

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Mod M
  External representations : Zo IO
  External representations : Zo OI
  Gero & Mc Neill : PS_Exploring a proposed solution
  Level of Abstraction : 2-Sub-Relations

Clip: RD Seg15
Collection: Design Process > MArch > RD-design process
Time: 0:06:41.3 - 0:06:51.2 (**Length:** 0:00:10.0)
Episode Transcript: richard2
Clip Transcript:
The dining space forms space around this *((Pointing at the Sc1 configuration))*.
Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Ref N
  Gero & Mc Neill : PS_Clarifying a P Solution_Details
  Level of Abstraction : 2-Sub-Relations

Clip: RD Seg16
Collection: Design Process > MArch > RD-design process
Time: 0:06:51.2 - 0:07:04.7 (**Length:** 0:00:13.5)
Episode Transcript: richard2
Clip Transcript:
Or dining space is part of that *((pointing at the front area of the Sc))* **seating area and the seating area is another part of that***((pointing at the left side of the Sc))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Ref N
External representations : Zo OI
Gero & Mc Neill : PS_Exploring a proposed solution
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg17
Collection: Design Process > MArch > RD-design process
Time: 0:07:04.7 - 0:07:32.4 (**Length:** 0:00:27.7)
Episode Transcript: richard2
Clip Transcript:
((pointing at the opposite corner and the pointing at the one that he has moved the Sc into))**Could be corner may be the kitchen addresses** *((rotating the Sc and move it towards the east southern corner))* **the dining space and seating area is separated from them to the South East** *((rotation Sc 1 and modifying Sc1 into Sc2 Linear shape))*

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Mod M
External representations : Mod VA
External representations : Ref N
External representations : Zo OI
Gero & Mc Neill : PS_Retracting a Previous Solution
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg18
Collection: Design Process > MArch > RD-design process
Time: 0:07:32.4 - 0:08:02.4 (**Length:** 0:00:30.0)
Episode Transcript: richard2
Clip Transcript:
May be a linear separation will give ..Do it simple *((rotate SC2 and move it))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Mod Gr
External representations : Mod M
External representations : Mod VA
Gero & Mc Neill : PS_Making a Design Decision
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg19
Collection: Design Process > MArch > RD-design process
Time: 0:08:02.4 - 0:08:29.0 (**Length:** 0:00:26.6)
Episode Transcript: richard2
Clip Transcript:
*((moving sc2 to the opposite corner intersecting with L4))***Perhaps**

the form of the building goes beyond the trees to the south because there is no relationship with the buildings it could *((draw L5 ,L6))***relate to the river slightly beyond the site boundary**
Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Crt N
  External representations : Mod M
  External representations : Ref G
  External representations : Ref N
  External representations : Zo IO
  External representations : Zo OI
  Gero & Mc Neill : PS_Proposing a Solution
  Level of Abstraction : 1-Design task

Clip: RD Seg20
Collection: Design Process > MArch > RD-design process
Time: 0:08:29.0 - 0:08:59.0   (**Length:** 0:00:30.0)
Episode Transcript: richard2
Clip Transcript:
=but the building footprint ((*pointing at the site layout***)) could still be within the boundary some sort of canopy could go to the south and create this outdoor seating area** *((moving and rotating Sc2 in relation to L4))*
Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Mod VA
  External representations : Ref G
  External representations : Ref N
  External representations : Zo IO
  External representations : Zo OI
  Gero & Mc Neill : PS_Exploring a proposed solution
  Level of Abstraction : 1-Design task

Clip: RD Seg21
Collection: Design Process > MArch > RD-design process
Time: 0:08:59.0 - 0:09:21.8   (**Length:** 0:00:22.7)
Episode Transcript: richard2
Clip Transcript:
*(delete Ds3))***the dining areas (***(pointing at 2*Ds))***, simply, could be unspecified areas that could be separated somehow** *((moving Sc2 near the centre then to the centre)*)
Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Mod D
  External representations : Mod M
  External representations : Ref N
  External representations : Zo OI
  Gero & Mc Neill : PS_Retracting a Previous Solution
  Level of Abstraction : 2-Sub-Relations

Clip: RD Seg22
Collection: Design Process > MArch > RD-design process
Time: 0:09:21.8 - 0:09:51.2   (**Length:** 0:00:29.5)
Episode Transcript: richard2
Clip Transcript:
The serving area could deliver along the fort ((move it near L4 then rotate it))the kitchen....

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Crt A
  External representations : Mod M
  External representations : Mod VA
  External representations : Ref N
  Gero & Mc Neill : PS_Clarifying a P Solution_Details
  Level of Abstraction : 2-Sub-Relations

Clip: RD Seg23
Collection: Design Process > MArch > RD-design process
Time: 0:09:51.2 - 0:10:24.9 (**Length:** 0:00:33.7)
Episode Transcript: richard2
Clip Transcript:
((rotating the Sc2 spaces)) **Or could be an extension of the kitchen ((modifying Sc2 into Sc3))**

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Crt A
  External representations : Mod Gr
  External representations : Mod VA
  Gero & Mc Neill : PS_Clarifying a P Solution_Details
  Level of Abstraction : 2-Sub-Relations

Clip: RD Seg24
Collection: Design Process > MArch > RD-design process
Time: 0:10:24.9 - 0:10:47.8 (**Length:** 0:00:22.9)
Episode Transcript: richard2
Clip Transcript:
So the dining area forms that part(*(pointing at the space left around the Sc3))* **with kitchen.. central kitchen** *((pointing at the central space of the Sc3 configuration))* **reaching out in to both sides and the central space** *((pointing at the area that is left of the main Triangular shape))*
Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Crt N
  External representations : Ref N
  External representations : Zo IO
  External representations : Zo OI
  Gero & Mc Neill : AS_Analysing a proposed Solution
  Level of Abstraction : 2-Sub-Relations

Clip: RD Seg 25
Collection: Design Process > MArch > RD-design process
Time: 0:10:47.8 - 0:11:29.3 (**Length:** 0:00:41.6)
Episode Transcript: richard2
Clip Transcript:
drawing L7,8,9,10 in order to form an overlapping shape between the trees sh2)) **It could also be an extension of.....canopy which addresses the school in a different way with the shape of the site***((changing the line type of the new shape 2 as same as the site layout-given-* delete *canopy 1))*

Clip Keywords:
  CAAD programs : AutoCAD

Drawing Types : 2D-CDiagram
External representations : Crt N
External representations : Mod D
Gero & Mc Neill : PS_Retracting a Previous Solution
Level of Abstraction : 1-Design task

Clip: RD Seg 26C
Collection: Design Process > MArch > RD-design process
Time: 0:11:29.3 - 0:11:57.9 (**Length:** 0:00:28.6)
Episode Transcript: richard2
Clip Transcript:
((change the lines properties ¤<714453>*((Delete Ds1 and Ds2, visual reference to the size of the required dining spaces))*

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Mod D
External representations : Mod P
Gero & Mc Neill : PS_Retracting a Previous Solution
Level of Abstraction : 1-Design task

Clip: RD Seg 27
Collection: Design Process > MArch > RD-design process
Time: 0:11:57.9 - 0:12:14.6 (**Length:** 0:00:16.7)
Episode Transcript: richard2
Clip Transcript:
So the spaces are created around this hub *((delete L2))* **(SD3)and the relationship is still kept between trees** *((zooming out and in))*

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Mod D
External representations : Ref G
External representations : Ref N
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Clarifying a P Solution_Repeat
Level of Abstraction : 1-Design task

Clip: RD Seg 28
Collection: Design Process > MArch > RD-design process
Time: 0:12:14.6 - 0:12:45.4 (**Length:** 0:00:30.8)
Episode Transcript: richard2
Clip Transcript:
The spaces that jut out from the central space (*(pointing at the triangular shape)*)**around the hub***((the service area))* **could be used for the display area**s *((pointing at the left spaces of Sh2))* **and part of this sculpture garden could come in to the building and relate to what is going on in the building**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Ref N
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Clarifying a P Solution_Details
Level of Abstraction : 1-Design task

Clip: RD Seg 29C
Collection: Design Process > MArch > RD-design process
Time: 0:12:45.4 - 0:12:54.2 (**Length:** 0:00:08.9)
Episode Transcript: richard2
Clip Transcript:
(*(zooming out and in to the site section))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw A
External representations : ChVw S
External representations : Insp G
Gero & Mc Neill : NA
Level of Abstraction : 0-Whole Site

Clip: RD Seg 30
Collection: Design Process > MArch > RD-design process
Time: 0:12:54.2 - 0:13:30.4 (**Length:** 0:00:36.2)
Episode Transcript: richard2
Clip Transcript:
Start to think about *((Adjusting the overlapping shape 2))* **how the building could be built, start to think about materials and how try not to affect its landscape its situation. Perhaps the simplest done with timber so the whole thing would be renewable and demountable**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Mod M
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : AS_Analysing a proposed Solution
Level of Abstraction : 1-Design task

Clip: RD Seg 31
Collection: Design Process > MArch > RD-design process
Time: 0:13:30.4 - 0:14:28.3 (**Length:** 0:00:57.9)
Episode Transcript: richard2
Clip Transcript:
((new layer: C Blue is given to Sh2))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw S
External representations : Crt N
External representations : Mod VA
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Clarifying a P Solution_Details
Level of Abstraction : NA

Clip: RD Seg 32
Collection: Design Process > MArch > RD-design process
Time: 0:14:28.3 - 0:14:59.9 (**Length:** 0:00:31.6)
Episode Transcript: richard2
Clip Transcript:
The shape of the building and the design at present almost, it is kind of *((drawing a column))***strange so perhaps we can.. and change that point within structure***((zooming out level 1))*

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Crt N
  External representations : Zo OI
  Gero & Mc Neill : AS_Analysing a proposed Solution
  Level of Abstraction : 1-Design task

Clip: RD Seg 33
Collection: Design Process > MArch > RD-design process
Time: 0:14:59.9 - 0:15:40.2 (**Length:** 0:00:40.3)
Episode Transcript: richard2
Clip Transcript:
(drawing an axis for the column [as a massing element],copy column and axis once to position it near the first one))

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Cpy N
  External representations : Crt C
  External representations : Mod VA
  External representations : Zo IO
  External representations : Zo OI
  Gero & Mc Neill : PS_Clarifying a P Solution_Details
  Level of Abstraction : 1-Design task

Clip: RD Seg 34
Collection: Design Process > MArch > RD-design process
Time: 0:15:40.2 - 0:16:09.1 (**Length:** 0:00:29.0)
Episode Transcript: richard2
Clip Transcript:
Perhaps if I got structure I wouldn't.. relate the shape as such wouldn't relate to the trees ((delete the copy))***there is almost this kind of try to minimize the structure where the tree in the closest points to the trees*** ((referring to the nearest points surrounding the northern tree))

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D-CDiagram
  External representations : Mod D
  External representations : Mod VA
  External representations : Ref G
  External representations : Zo IO
  External representations : Zo OI
  Gero & Mc Neill : AS_Evaluating a Proposed Solution
  Level of Abstraction : 3-Design Entity

Clip: RD Seg 35
Collection: Design Process > MArch > RD-design process
Time: 0:16:09.1 - 0:17:40.4 (**Length:** 0:01:31.2)
Episode Transcript: richard2
Clip Transcript:
((Zooming in to the column

¤<993163>to copy it once again, more further to the right side of the site, extend the axis to intersect with the canopy shape))

Clip Keywords:

CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Cpy N
External representations : Mod D
Gero & Mc Neill : PS_Retracting a Previous Solution
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg 36
Collection: Design Process > MArch > RD-design process
Time: 0:17:40.4 - 0:18:39.6 (**Length:** 0:00:59.3)
Episode Transcript: richard2
Clip Transcript:
There is the possibility that they are making it like there is no structure near the trees and the edges become glazed so the trees aren't affected by what is going on the ground whether they look like or not *((zooming in and out: level 1-2))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Mod D
External representations : Ref G
External representations : Ref N
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Retracting a Previous Solution
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg 37
Collection: Design Process > MArch > RD-design process
Time: 0:18:39.6 - 0:19:26.7 (**Length:** 0:00:47.1)
Episode Transcript: richard2
Clip Transcript:
*((Zooming out and in, looking))***Perhaps just..secondary glass the structure** *((drawing Sh3 lines along Sh1 and the overlapping sh2 and the given rectangle site))* **back from the glazed screen is a simple way of doing it/that**

((defining shape 3 (Sh3) as a result of the intersecting shapes Sh1 , Sh2 and the given site))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt C
External representations : Crt N
External representations : Mod Aj
Gero & Mc Neill : PS_Proposing a Solution
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg 38
Collection: Design Process > MArch > RD-design process
Time: 0:19:26.7 - 0:20:33.4 (**Length:** 0:01:06.7)
Episode Transcript: richard2
Clip Transcript:
*((offset sh3 and new layer: green))***The glazing we want to mask structure which would occur beyond it ......**

((looking and zooming in to level2))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt C

External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Modifying a solution
Level of Abstraction : 3-Design Entity

Clip: RD Seg 39
Collection: Design Process > MArch > RD-design process
Time: 0:20:33.4 - 0:21:06.1 (**Length:** 0:00:32.7)
Episode Transcript: richard2
Clip Transcript:
(zooming to level 2)) **perhaps glazing could be structural itself(***(zooming in to level3))***,or perhaps just do it simple/be simple...solution***((zooming out to level 1))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt A
External representations : Crt C
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Making a Design Decision
Level of Abstraction : 3-Design Entity

Clip: RD Seg 40
Collection: Design Process > MArch > RD-design process
Time: 0:21:06.1 - 0:23:22.1 (**Length:** 0:02:16.0)
Episode Transcript: richard2
Clip Transcript:
*((new layer, adding text))***Thinking to start putting in text menial kind of tasks to bring us the chance to think about other things it is almost like a break from my brain**

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt Tx
Gero & Mc Neill : EX_Referring to CAD Strategy
Level of Abstraction : NA

Clip: RD Seg 41
Collection: Design Process > MArch > RD-design process
Time: 0:23:22.1 - 0:23:54.4 (**Length:** 0:00:32.3)
Episode Transcript: richard2
Clip Transcript:
*((zooming in and out between level 1-2))***May be the glass could be beyond.. into this..Display area***((defining a space on one side of Sh3 by tracing Sh 2,Zooming in and out L1-2))*

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt C
External representations : Crt N
External representations : Ref N
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Modifying a solution
Level of Abstraction : 2-Sub-Relations

Clip: Rg Seg 42

Collection: Design Process > MArch > RD-design process
Time: 0:23:54.4 - 0:24:14.6 (**Length:** 0:00:20.2)
Episode Transcript: richard2
Clip Transcript:
((doing the same to the other end, to define another space on the other side))

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt N
External representations : Ref N
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Clarifying a P Solution_Repeat
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg 43
Collection: Design Process > MArch > RD-design process
Time: 0:24:14.6 - 0:25:04.8 (**Length:** 0:00:50.2)
Episode Transcript: richard2
Clip Transcript:
That*((the display area, intended to use the whole Triangular space))* k**ind takes away this flat edge that and hopefully it acts as an entrance and draw people in from the schools***((offset Sh 3))***and this bigger than it actually ....**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Cpy G
External representations : Crt A
External representations : Ref N
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : AS_Analysing a proposed Solution
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg 44
Collection: Design Process > MArch > RD-design process
Time: 0:25:04.8 - 0:25:36.2 (**Length:** 0:00:31.4)
Episode Transcript: richard2
Clip Transcript:
Perhaps it could just go slightly beyond *((offset another line and delete the previous one))***and create smaller display area which relates to the sculpture garden** *((drawing line referring to the entrance))***a...and entrance**

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt N
External representations : Mod D
External representations : Mod VA
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Modifying a solution
Level of Abstraction : 3-Design Entity

Clip: RD Seg 45
Collection: Design Process > MArch > RD-design process

Time: 0:25:36.2 - 0:26:04.1 (**Length:** 0:00:27.9)
Episode Transcript: richard2
Clip Transcript:
(modifying sh3 in relation to sh2-Z in to L3))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Mod Aj
Gero & Mc Neill : PS_Modifying a solution
Level of Abstraction : 3-Design Entity

Clip: RD Seg 46
Collection: Design Process > MArch > RD-design process
Time: 0:26:04.1 - 0:26:38.4 (**Length:** 0:00:34.2)
Episode Transcript: richard2
Clip Transcript:
((Deleting the previous repeated lines in a trial to repeat the same detail of the left side entrance))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Cpy N
External representations : Mod D
Gero & Mc Neill : PS_Clarifying a P Solution_Repeat
Level of Abstraction : 3-Design Entity

Clip: RD Seg 47
Collection: Design Process > MArch > RD-design process
Time: 0:26:38.4 - 0:27:25.1 (**Length:** 0:00:46.8)
Episode Transcript: richard2
Clip Transcript:
This display area also acts as double separation between an internal area and an external area*((draw the other entrance direction))*

((zooming in and out from L2 to-1))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Crt A
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Clarifying a P Solution_Repeat
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg 48
Collection: Design Process > MArch > RD-design process
Time: 0:27:25.1 - 0:28:11.7 (**Length:** 0:00:46.6)
Episode Transcript: richard2
Clip Transcript:
As the site is on the slope and viewed from above these areas *((pointing at the two entrances))***that address the buildings in 3D they are actually tilt-up and allowed the passive eye to see beyond the facade of the building within so they actually would see what is going on in the building, otherwise they just see a tree and a roof, I think tilting these** *((roof parts that covers and define the two entrances))* **up almost signal that something is going on....**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : Mod Aj
External representations : Ref N

External representations : Verb_Idea
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : AS_Evaluating a Proposed Solution
Level of Abstraction : 0-Whole Site

Clip: RD Seg 49
Collection: Design Process > MArch > RD-design process
Time: 0:28:11.7 - 0:28:48.1 (**Length:** 0:00:36.4)
Episode Transcript: richard2
Clip Transcript:
((focusing back on the detailed level of the right side entrance))
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-CDiagram
External representations : ChVw S
External representations : Crt N
External representations : Mod M
External representations : Mod VA
External representations : Ref G
Gero & Mc Neill : PS_Clarifying a P Solution_Repeat
Level of Abstraction : 3-Design Entity

Clip: RD Seg 50
Collection: Design Process > MArch > RD-design process
Time: 0:28:48.1 - 0:29:59.1 (**Length:** 0:01:11.0)
Episode Transcript: richard2
Clip Transcript:
*((zooming in and out))***we may be draw a section line** *((extending the entrance line))* **which hopefully...Tell me how much we need to tilt the roof. What are the differences between these section lines..?aa..No the contors, can/ Do you know? 10 meters? More......***((looking at the site section))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : ChVw A
External representations : Crt N
External representations : Mod P
Gero & Mc Neill : PS_Consulting External Information
Level of Abstraction : 1-Design task

Clip: RD Seg 51
Collection: Design Process > MArch > RD-design process
Time: 0:29:59.1 - 0:31:44.4 (**Length:** 0:01:45.4)
Episode Transcript: richard2
Clip Transcript:
((Drawing section ,projecting the building))¤<1856188>
¤<1858947>copy the resulted section to a new location and rotate then delete))

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : ChVw S
External representations : Crt N
External representations : Insp G
External representations : Insp P
External representations : Zo IO
Gero & Mc Neill : Ex_Practically Working on CAD

Level of Abstraction : 1-Design task

Clip: RD Seg 52
Collection: Design Process > MArch > RD-design process
Time: 0:31:44.4 - 0:33:24.5 (**Length:** 0:01:40.1)
Episode Transcript: richard2
Clip Transcript:
((back to the section and rotate the whole site))**I am trying to start from the point..***((working on the roof))* **so at this point would be 5 meters above,......the site is flattening quite a bit, .. can estimate.**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : Crt N
External representations : Mod D
External representations : Mod M
External representations : Mod VA
Gero & Mc Neill : PS_Consulting External Information
Level of Abstraction : 0-Whole Site

Clip: RD Seg 53
Collection: Design Process > MArch > RD-design process
Time: 0:33:24.5 - 0:33:44.8 (**Length:** 0:00:20.3)
Episode Transcript: richard2
Clip Transcript:
knowing that there is 10 meters difference from the actual viewing height and other buildings
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : Crt N
Gero & Mc Neill : PS_Consulting External Information
Level of Abstraction : 3-Design Entity

Clip: RD Seg 53-1
Collection: Design Process > MArch > RD-design process
Time: 0:33:44.8 - 0:34:45.7 (**Length:** 0:01:00.9)
Episode Transcript: richard2
Clip Transcript:
((copied the given figure))**so for a person to stand on the corner ..the head..its kind see what how much they are able to see, how high this roof would be, is needed to be raise**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : Cpy G
Gero & Mc Neill : AS_Calculating on a Proposed Solution
Level of Abstraction : 1-Design task

Clip: RD seg 54
Collection: Design Process > MArch > RD-design process
Time: 0:34:45.7 - 0:35:40.7 (**Length:** 0:00:54.9)
Episode Transcript: richard2
Clip Transcript:
((copy the whole site level-1)) **I think this roof come back to the structure line(***(working on the roof height))***; the angle would be allowed the user to see the display area, sculpture garden**
Clip Keywords:
CAAD programs : AutoCAD

Drawing Types : 2D-ISection
External representations : ChVw A
External representations : Insp P
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : AS_Analysing a proposed Solution
Level of Abstraction : 3-Design Entity

Clip: RD Seg 55
Collection: Design Process > MArch > RD-design process
Time: 0:35:40.7 - 0:37:47.1 (**Length:** 0:02:06.5)
Episode Transcript: richard2
Clip Transcript:
[draws the other roof of the back side of the building]
¤<2153273>**I think this back area could also tilt up to kind catch the light comes through, the bank of trees. Give the seating area that aspect rather than shelter, tilt to ..upon the structure. Then up again***((drawing the back tilted roof))* **...tilt to the point of the structure**

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : Cpy N
External representations : Crt N
External representations : Insp P
Gero & Mc Neill : PS_Clarifying a P Solution_Repeat
Level of Abstraction : 3-Design Entity

Clip: RD Seg 56
Collection: Design Process > MArch > RD-design process
Time: 0:37:47.1 - 0:38:27.7 (**Length:** 0:00:40.6)
Episode Transcript: richard2
Clip Transcript:
[drawing the inner section lines]**The building seems to get a bit of form now rather than just being a plan** *((cleaning the section lines))*

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : Crt N
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : AS_Evaluating a Proposed Solution
Level of Abstraction : 1-Design task

Clip: RD Seg 57C
Collection: Design Process > MArch > RD-design process
Time: 0:38:27.7 - 0:38:58.5 (**Length:** 0:00:30.8)
Episode Transcript: richard2
Clip Transcript:
*((deleting))***construction lines-** ¤<2326388>**It kind becomes visible is to delete the structure construction lines ((finishing the section))**

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : Crt A
External representations : Mod D

External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : Ex_Practically Working on CAD
Level of Abstraction : 3-Design Entity

Clip: RD Seg 58
Collection: Design Process > MArch > RD-design process
Time: 0:38:58.5 - 0:39:45.4 (**Length:** 0:00:46.9)
Episode Transcript: richard2
Clip Transcript:
((moving the resulted section into other location near the given site section))¤<2364096>**(0:39:24.1)**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : Mod VA
External representations : New D
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : Ex_Practically Working on CAD
Level of Abstraction : 1-Design task

Clip: RD Seg 59
Collection: Design Process > MArch > RD-design process
Time: 0:39:45.4 - 0:41:58.0 (**Length:** 0:02:12.6)
Episode Transcript: richard2
Clip Transcript:
*((copying the trees in relation to the building-section))***It probably shows the trees and the relationship between the trees and the building site.)**¤<2447873>(0:40:47.9) **It kind shows that the building relates to something rather than sitting by its own** *((delete the reference tree))*
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D-ISection
External representations : Cpy G
External representations : Cpy N
External representations : Crt N
External representations : Ref G
Gero & Mc Neill : Ex_Practically Working on CAD
Level of Abstraction : 1-Design task

Clip: RD Seg 60
Collection: Design Process > MArch > RD-design process
Time: 0:41:58.0 - 0:44:12.3 (**Length:** 0:02:14.3)
Episode Transcript: richard2
Clip Transcript:
*((Isometric view, copying plan and located outside the main site layout, extruding the building sides, solid))***I could have also to start the 3D, quite simple I think**
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D/3D-Modeling
External representations : ChVw A
External representations : Mod 3D
External representations : Vw Iso
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : PS_Clarifying a P Solution_Details
Level of Abstraction : 1-Design task

Clip: RD Seg 61
Collection: Design Process > MArch > RD-design process
Time: 0:44:12.3 - 0:46:16.5 (**Length:** 0:02:04.2)
Episode Transcript: richard2
Clip Transcript:
The roof itself quite difficult to show in 3Dimentions because of the twist and....

¤<2670201>*((tracing the flat part of the roof on the plan, defining the solid plane for it))*¤<2754956>**This is the flat part of the roof**

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D/3D-Modeling
External representations : Crt N
External representations : Crt Tc
External representations : Mod 3D
External representations : Mod M
External representations : Mod VA
Gero & Mc Neill : EX_Referring to CAD Strategy
Level of Abstraction : 2-Sub-Relations

Clip: RD Seg 62
Collection: Design Process > MArch > RD-design process
Time: 0:46:16.5 - 0:48:03.5 (**Length:** 0:01:47.1)
Episode Transcript: richard2
Clip Transcript:
(trying to draw the tilted roof))***The section can show us how the roof works, I don't know where...***
¤<2806740>(0:46:46.7)**(**(tracing the tilted roof wings on the plan and move them beside the proposed 3D))¤<2863521>(0:47:43.5)
Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 2D/3D-Modeling
External representations : Crt Tc
External representations : Ref N
Gero & Mc Neill : EX_Referring to CAD Strategy
Level of Abstraction : 3-Design Entity

Clip: RD Seg 63
Collection: Design Process > MArch > RD-design process
Time: 0:48:03.5 - 0:48:22.9 (**Length:** 0:00:19.4)
Episode Transcript: richard2
Clip Transcript:
(extruding them then moving them to the modelled concept))

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 3D-PModelling
External representations : Mod 3D
External representations : Mod M
External representations : Mod VA
Gero & Mc Neill : EX_Referring to CAD Strategy
Level of Abstraction : 3-Design Entity

Clip: RD Seg 64
Collection: Design Process > MArch > RD-design process
Time: 0:48:22.9 - 0:50:26.2 (**Length:** 0:02:03.3)
Episode Transcript: richard2
Clip Transcript:

[moving them to the 3D as plane roofs]

To start to think of a way to extruding something or doing something in AutoCAD rotating something to the right angle, it is kind of long drawing process, when you can simply draw it and sketch it but then this could be used again and again so it is worth it.

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 3D-PModelling
  External representations : Crt C
  External representations : Mod M
  Gero & Mc Neill : EX_Referring to CAD Strategy
  Level of Abstraction : 4-Detail

Clip: RD Seg 65
Collection: Design Process > MArch > RD-design process
Time: 0:50:26.2 - 0:52:35.5 (**Length:** 0:02:09.3)
Episode Transcript: richard2
Clip Transcript:
[looking for the angle degrees from the section]

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 2D/3D-Modeling
  External representations : Crt C
  Gero & Mc Neill : PS_Consulting External Information
  Level of Abstraction : 4-Detail

Clip: RD Seg 66
Collection: Design Process > MArch > RD-design process
Time: 0:52:35.5 - 0:55:06.5 (**Length:** 0:02:31.0)
Episode Transcript: richard2
Clip Transcript:
[rotating the wings accordingly]

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 3D-PModelling
  External representations : Mod 3D
  Gero & Mc Neill : Ex_Practically Working on CAD
  Level of Abstraction : 4-Detail

Clip: RD Seg 67
Collection: Design Process > MArch > RD-design process
Time: 0:55:06.5 - 0:56:37.6 (**Length:** 0:01:31.1)
Episode Transcript: richard2
Clip Transcript:
How far should I go? .....ok ok . Can’t talk anymore I am just coming doing stuff.

Clip Keywords:
  CAAD programs : AutoCAD
  Drawing Types : 3D-PModelling
  External representations : Mod 3D
  Gero & Mc Neill : Ex_Practically Working on CAD
  Level of Abstraction : 4-Detail

Clip: RD Seg 68
Collection: Design Process > MArch > RD-design process

Time: 0:56:37.6 - 0:57:28.1 (**Length:** 0:00:50.4)
Episode Transcript: richard2
Clip Transcript:
((finish and start to exploring the finished 3D))

Clip Keywords:
CAAD programs : AutoCAD
Drawing Types : 3D-PModelling
External representations : Vw Iso
External representations : Zo IO
External representations : Zo OI
Gero & Mc Neill : AS_Evaluating a Proposed Solution
Level of Abstraction : 1-Design task

Summary

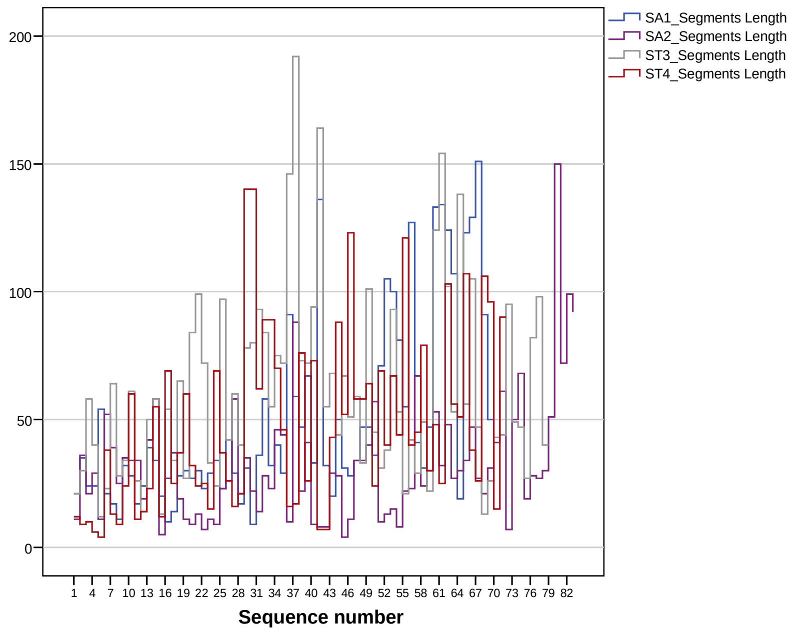
CAAD programs : AutoCAD	70	0:57:28.1
Drawing Types : 2D-CDiagram	50	0:28:48.1
Drawing Types : 2D-ISection	11	0:13:09.9
Drawing Types : 2D/3D-Modeling	4	0:08:14.9
Drawing Types : 3D-PModelling	5	0:07:15.2
External representations : ChVw A	5	0:04:50.3
External representations : ChVw S	12	0:06:29.7
External representations : Cpy G	4	0:04:27.7
External representations : Cpy N	5	0:07:04.8
External representations : Crt A	6	0:03:43.7
External representations : Crt C	10	0:09:11.6
External representations : Crt G	2	0:01:10.7
External representations : Crt N	24	0:21:05.9
External representations : Crt Tc	2	0:03:51.3
External representations : Crt Tx	1	0:02:16.0
External representations : Insp G	4	0:03:19.7
External representations : Insp P	3	0:04:46.8
External representations : Mod 3D	5	0:08:40.0
External representations : Mod Aj	3	0:02:01.6
External representations : Mod D	11	0:08:05.5
External representations : Mod Gr	2	0:01:03.7
External representations : Mod M	14	0:11:09.2
External representations : Mod P	2	0:01:39.5
External representations : Mod VA	15	0:11:10.5
External representations : New D	1	0:00:46.9
External representations : Ref G	12	0:07:43.8
External representations : Ref N	19	0:10:15.6
External representations : Verb_Idea	4	0:02:25.8
External representations : Vw Iso	2	0:03:04.8
External representations : Zo IO	30	0:20:56.3
External representations : Zo OI	35	0:21:25.6
Gero & Mc Neill: AP_Analysing the Problem	3	0:01:09.6
Gero & Mc Neill: AP_Consulting Information about the Problem	2	0:00:59.3
Gero & Mc Neill : AP_Evaluating the Problem	1	0:00:21.3
Gero & Mc Neill : AS_Analysing a proposed Solution	6	0:03:33.3
Gero & Mc Neill : AS_Calculating on a Proposed Solution	1	0:01:00.9
Gero & Mc Neill : AS_Evaluating a Proposed Solution	4	0:02:46.5
Gero & Mc Neill : EX_Referring to CAD Strategy	5	0:08:29.9
Gero & Mc Neill : Ex_Practically Working on CAD	7	0:09:41.7
Gero & Mc Neill : NA	1	0:00:08.9
Gero & Mc Neill : PS_Clarifying a P Solution_Details	9	0:06:40.0
Gero & Mc Neill : PS_Clarifying a P Solution_Repeat	6	0:04:40.7
Gero & Mc Neill : PS_Consulting External Information	4	0:05:20.7
Gero & Mc Neill : PS_Exploring a proposed solution	3	0:01:03.4
Gero & Mc Neill : PS_Making a Design Decision	2	0:01:02.8
Gero & Mc Neill : PS_Modifying a solution	4	0:02:38.3

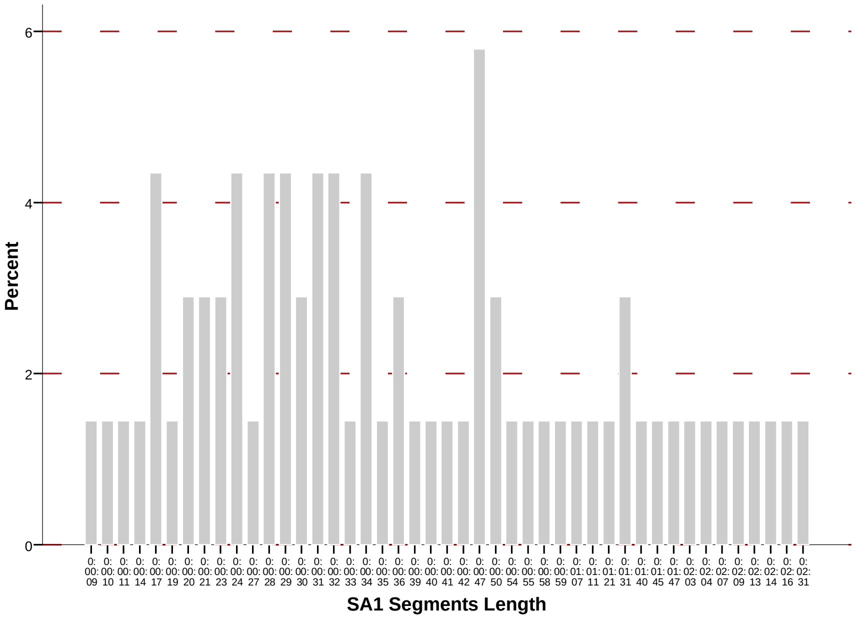
Gero & Mc Neill : PS_Proposing a Solution	7	0:03:43.7
Gero & Mc Neill : PS_Retracting a Previous Solution	6	0:04:31.0
Level of Abstraction : 0-Whole Site	9	0:05:30.5
Level of Abstraction : 1-Design task	21	0:16:48.2
Level of Abstraction : 2-Sub-Relations	20	0:13:02.3
Level of Abstraction : 3-Design Entity	13	0:10:17.2
Level of Abstraction : 4-Detail	4	0:08:14.7
Level of Abstraction : NA	2	0:03:13.8

Clips: 71 **Total Time: 1:10:31.9**

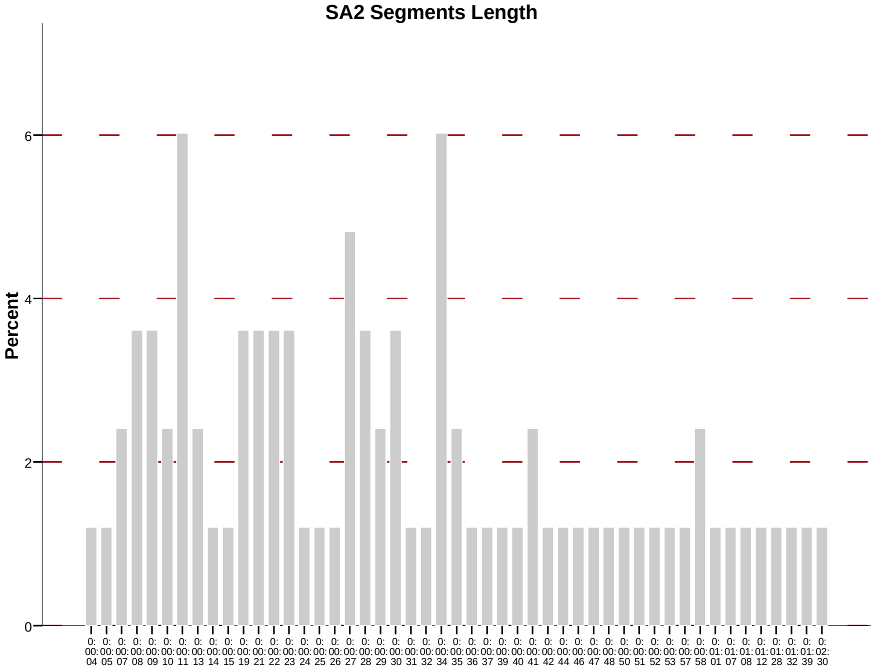
Appendix G3: Segments duration and Graphs

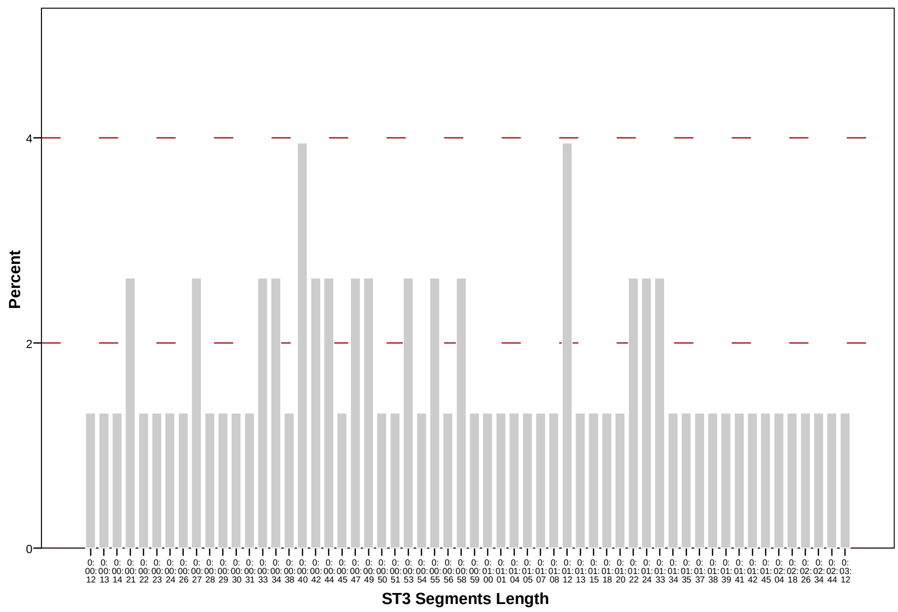
Case SA1 duration was average (0:57:28) with the lowest number of segments (69) compare to the other cases and a high mean of segment length of 49 sec. ST4 Average duration 00:53:34 with a high number 71 of segments and a high mean segment length of 44 sec. SA2 Shortest duration 0:45:18 with the highest number 83 of segments and the lowest mean segment length of 32 sec. ST3 longest duration 01:19:41 with a high number 76 of segments and highest mean segment length of 1 minute and 2 sec.



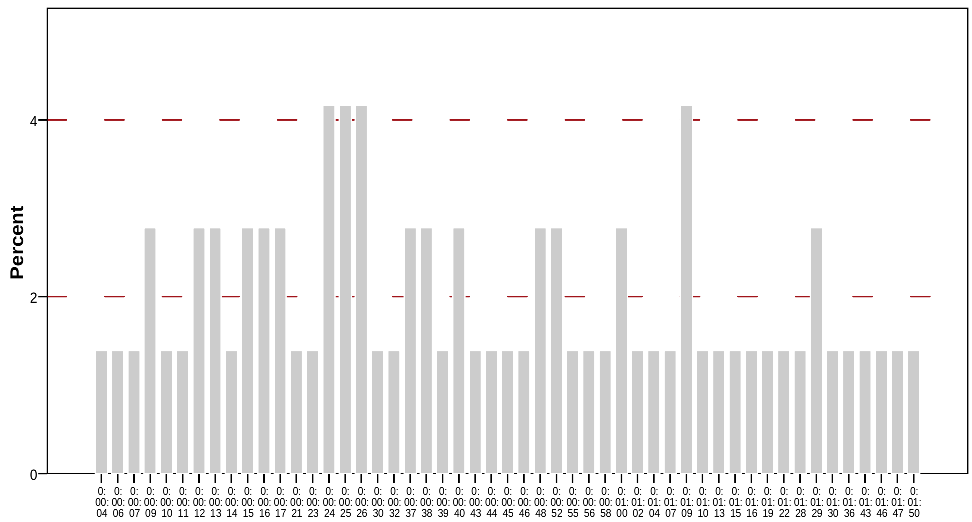


SA2 Segments Length



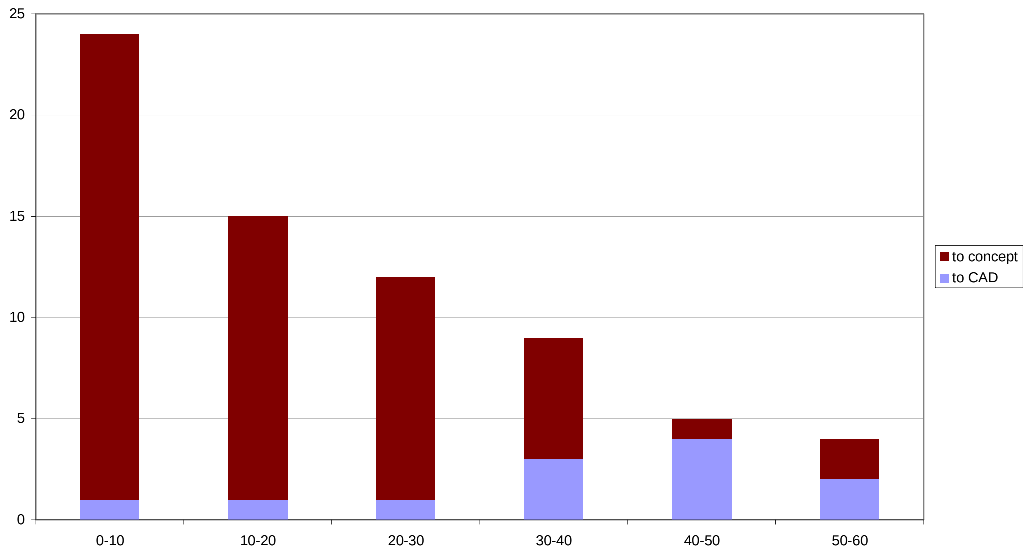


ST4 Segments Length

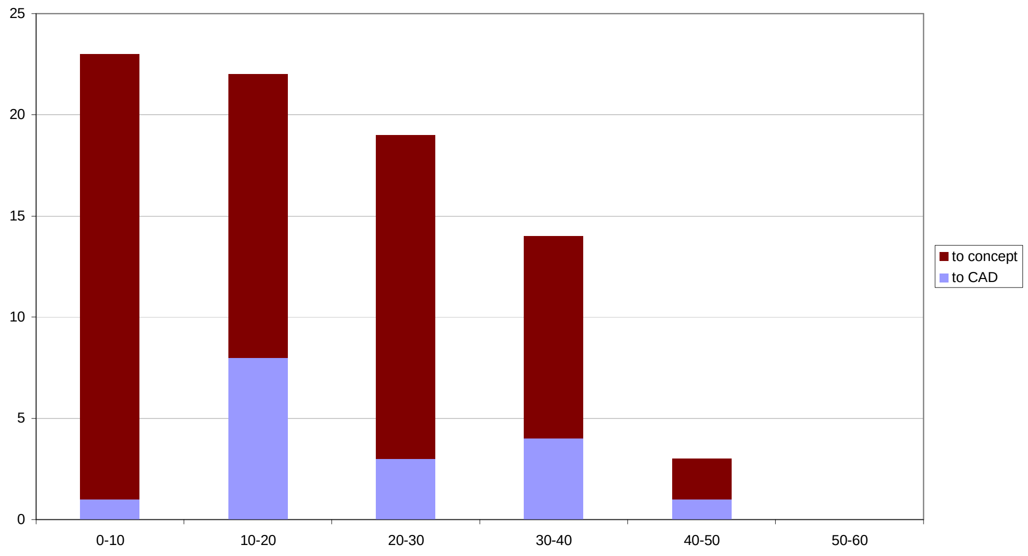


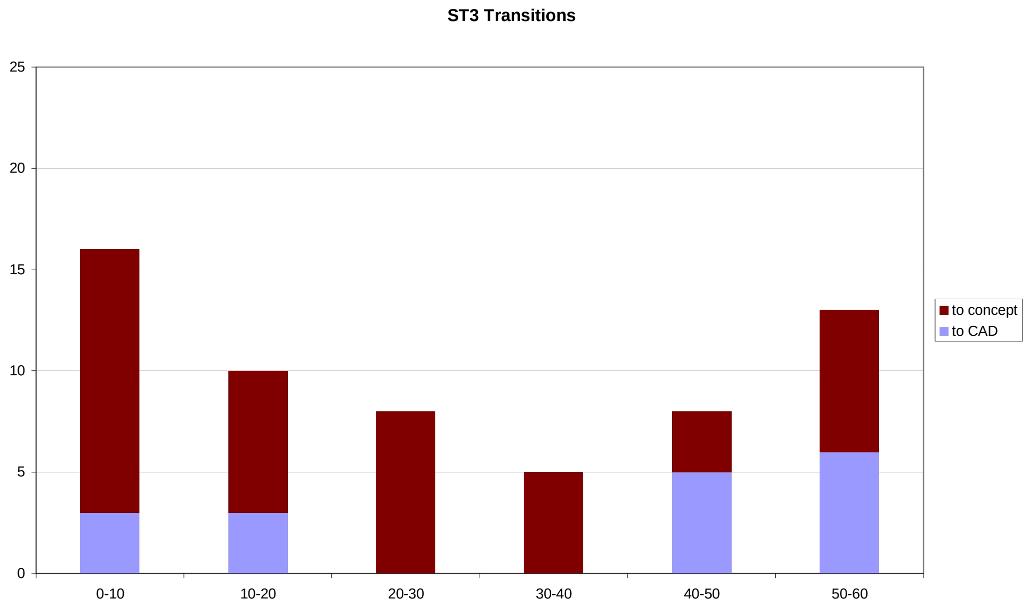
Appendix G4: Tables of the Transition rate between CAD segments and Concept

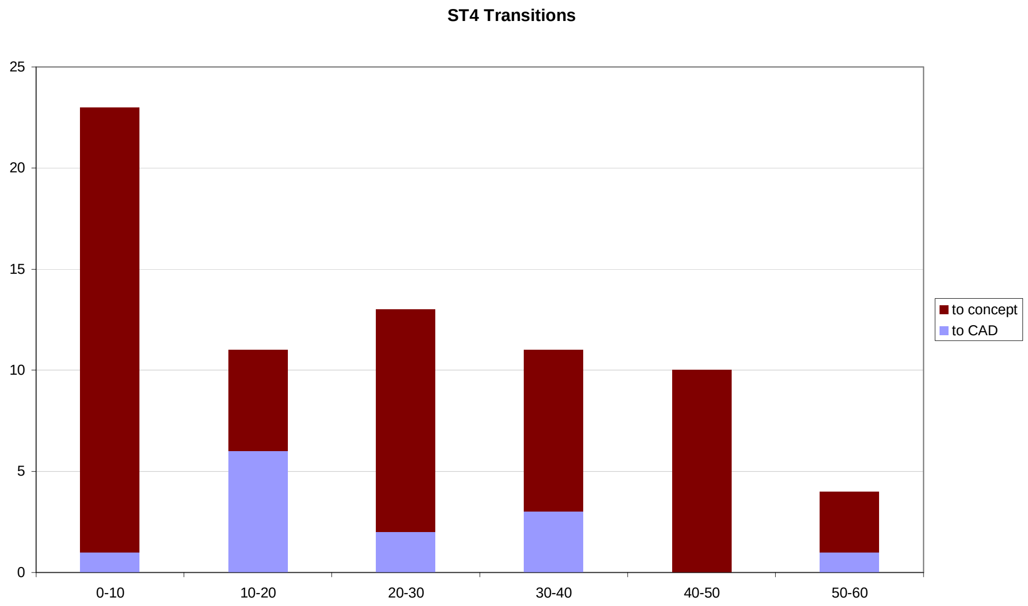
SA1 transitions to CAAD/To Concept in every 10 minutes interval



SA2 Trans



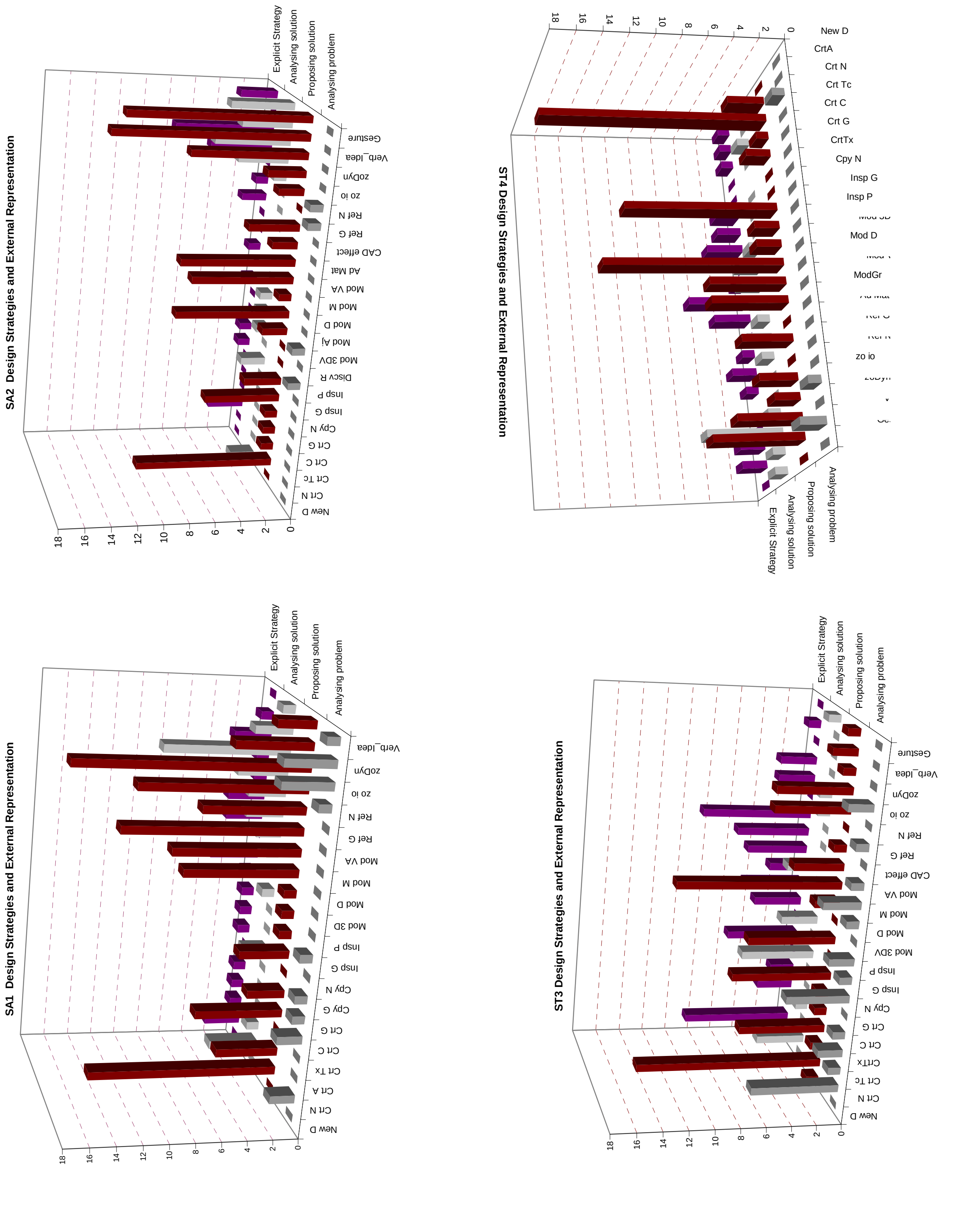




Appendix G5: Level of abstraction Percentages Table

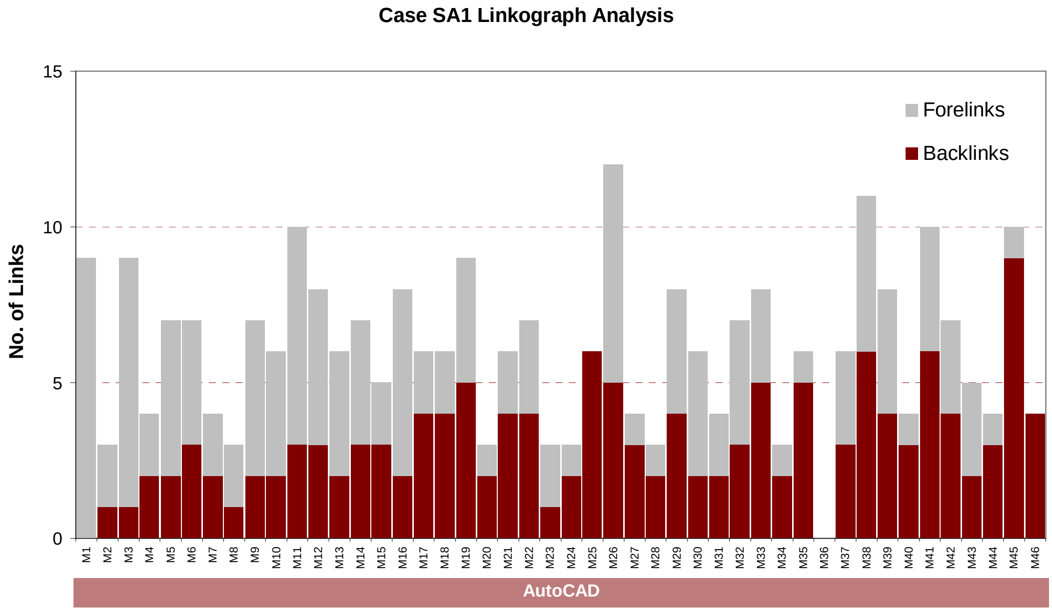
Level of Abstraction	*SA1*	*SA2*	*ST3*	*ST4*	*Average*
Level 0	10%	4%	3%	1%	4%
Level 1	**29**%	18%	**25**%	12%	21%
Level 2	**23**%	**32%**	**25**%	**29%**	**27%**
Level 3	18%	**31%**	13%	**35%**	**24%**
Level 4	15%	4%	29%	22%	17%
NA	6%	11%	6%	2%	6%
	100%	100%	100%	100%	100%

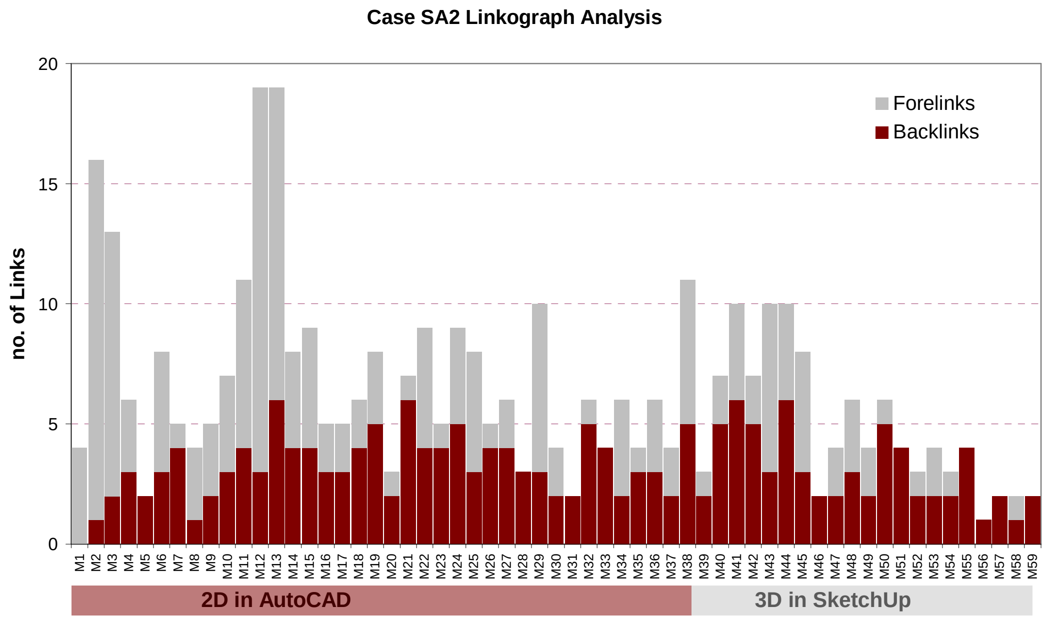
Appendix G6: External Representation Acts Graphs

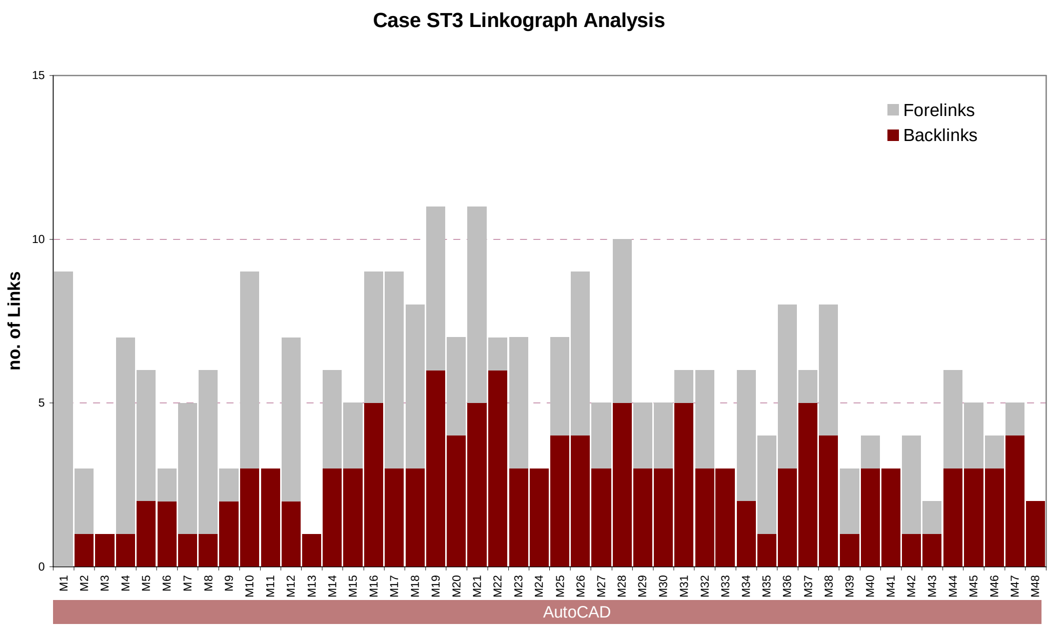


3D bar charts Metrics of the four cases to explain the relation between the design process strategies and external representation actions.

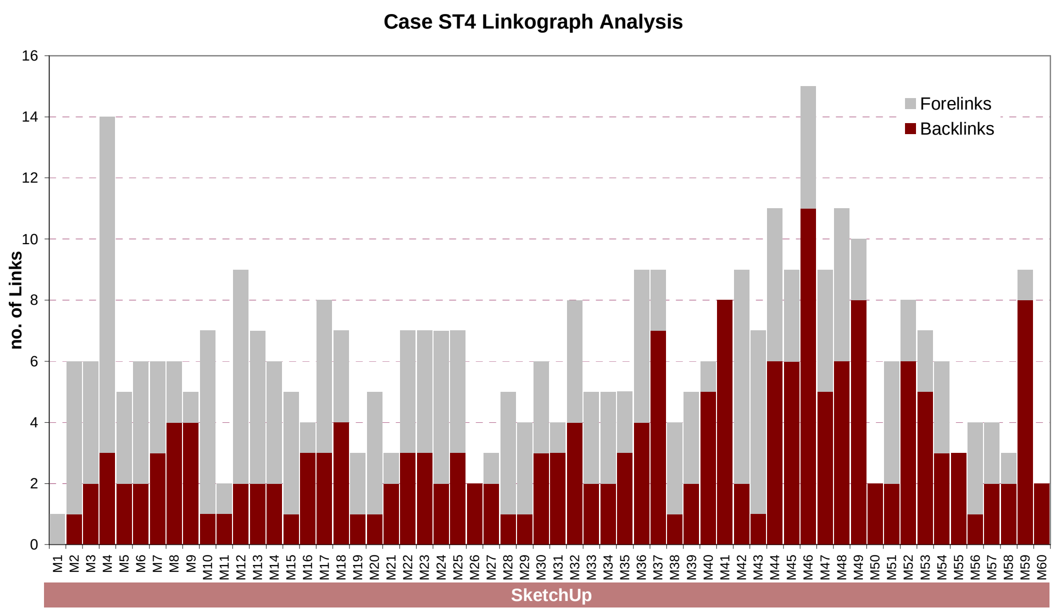
Appendix G7 Linkography design moves backlinks and forelinks for the four cases







Case ST3 Linkograph Analysis
Forelinks
Backlinks
no. of Links
AutoCAD



Case ST4 Linkograph Analysis
Forelinks
Backlinks
no. of Links
SketchUp

Appendix G8 Linkography Coding

Examples on implicit association among design moves

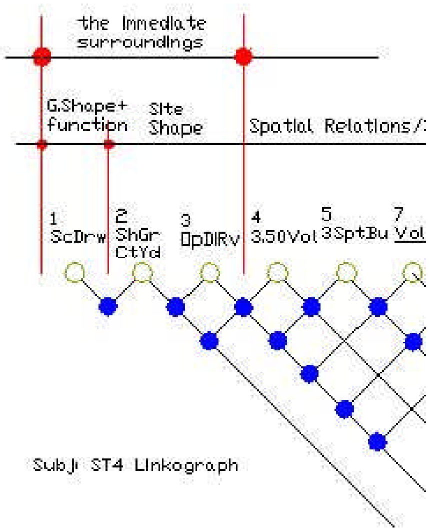
In the cases of SA1 and SA2 the participant asked a question to gather to generate certain information on which the subsequent action (solution) was based. So the design move (answer-based) has a dependency on the first action (question-based) and changed the status of the design in relation to the answer, thus both actions are considered as design moves within the design process structure and productivity.

Firstly when the participant asked a question, is it considered as a design move and why? Yes it is considered a as design move because the gathered information become part of the design situation and any subsequent move would take it into consideration.

One example of determining the implicit association between two design moves is the participant's question in the case of SA1 and SA2 is considered The participant asked a question to generate missing information that he needs as part of the design situation, on which the subsequent action (solution) was based. So the design move (answer-based) has a dependency on the first action (question-based) and has changed the status of the design in relation to the answer; thus, both actions are considered as design moves within the design process structure and productivity.

In the case of ST4

In the move no.2 he said "*Immediately I get the feeling of a shape that [more] of Gray's [one of the surrounding buildings/Art school] to create a courtyard",* by mentioning courtyard he decided two things implicitly for the proposed design: assigning the positive spaces and the negative spaces of the site (outdoor/indoor), and the shape (squared shape). Such move (decision) implies that the participant has considered the brief requirements and cognized that such proposition is useful in solving the design problem.

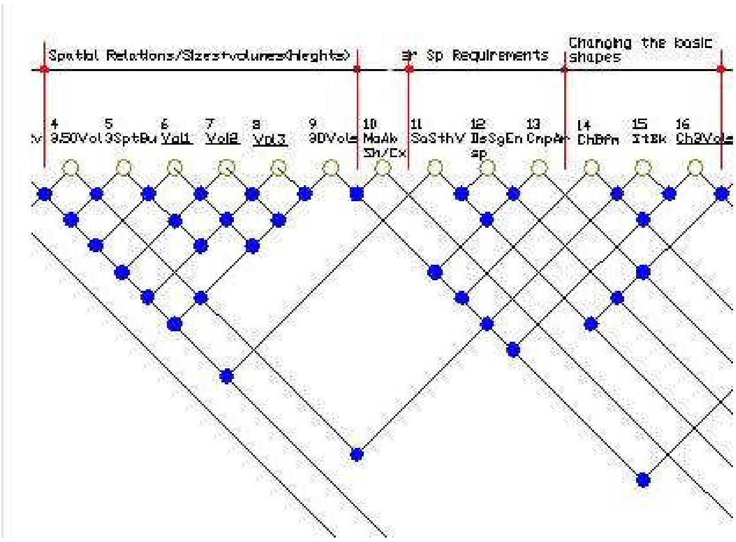


In Move 3: "*but probably an open courtyard in the direction of the river*" he clarifies the courtyard (normally it is a negative area defined by the surrounding facades, whether walls or buildings) by two things: *open* (defined by three sides only) and *in the direction of the river*, as apposed to Gray's courtyard. It is clear that Move 3 is dependent on move 2.

Then the student mentioned in move 4 "*..with three fifty-metre volumes creating the effect*". In a trial to roughly define the positive space in move 2, he specifies the height (volumes) on the 3D level, to compliment the shape that he mentioned in move 2 and at the same time defines the three sided courtyard. In the coming move (no 5) he continues in defining the 3D proposed design "*It might be three separate buildings*". And it is also dependant implicitly on moves three and four; the word "*three*" is an indicator to move 3 and the "*building*" (construction, structure) is an indicator to move 4.

Another unit of the design process was concerned with the spatial requirements. In move 12 "*Yah - twenty-metre display area.[referring to the courtyard created by the three buildings.] I suppose that could be a single* ***enclosed space***". So the courtyard has changed into an enclosed space as a result of the spatial/functional requirements.

In move 13, the participant also emphasised the basic form rather than the courtyard. "*So, aligned to, say, this basic form, we could possibly put... a canopied area between the two and that could include both the art display area and the sculpture garden which is another fifty-metres space, plus a kitchen and a canteen*". The enclosed space ha changed into a canopied area, which implies defining a semi outdoor space (merging courtyard and enclosed space into canopied area. And theses in linkographic terminology are associated and dependant.



On the other hand, the ensuing move no 14 was not dependent on the previous two, but dependant on move no 9 where the basic forms were created (extruded). The participant considered the visual feedback of the previous design unit to shift his thoughts from the spatial functional requirements to how the basic form looks "*amm ..I think we need to change the basic form of this*". In move 15 he clarifies what he meant by changing the form and by which aspect "*This is the side which is tilted up towards the bank. We could do a design which has a more impact on the height rather than current in here!*" These later moves (14 and 15) are dependant moves and both are associated with move no 9. However, move no 15 has an association with move no 4, as both are associated by the same clarified aspect; the **height** of the building.

One difference between design protocol and linkograph coding is the time spent on a design move or time relative dependency between one move and another.
In linkography if the time spent on designing was to be considered, then the time intervals of a design move and an ensuing move should be considered as an association between the former move and the ensuing move of a design unit, as a result all the independent moves will have an association of the process time frame.