Understanding the Changes of Designers' Behaviours when Using Mixed Media Design Environments

By

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Declarations

Originality

I hereby certify that to the best of my knowledge and belief this thesis is my own work and contains no material previously published or written by another person except where due references and acknowledgements are made. It contains no material which has been previously submitted by me for the award of any other degree or diploma in any university or other tertiary institution.

Thesis by Publication

*I hereby certify that this thesis is in the form of a series of *papers. I have included as part of the thesis a written statement from each co-author, endorsed in writing by the Faculty Assistant Dean (Research Training), attesting to my contribution to any jointly authored papers.*

*(*Refer to clause 39.2 of the Rules Governing Research Higher Degrees for acceptable papers).*

(Yi Teng Shih)

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Abstract

Designers' interactions with design media have shifted from individual to multiple design media to improve design activities and outcomes. This transition is mainly in response to the increased globalisation of design projects. However, many mixed media studies have adopted a linear approach and focused on evaluating design solutions from different design media as opposed to design processes. Different uses of design media during designing may influence designers' cognition and design processes. In previous mixed media empirical studies, designers were asked to initially use traditional sketching before shifting to CAD modelling. For the purpose of the study, this use of mixed media, in which one shift between media occurs, is defined as Sequential Mixed Media (SMM). However, designers prefer to interact freely between media, alternating between sketching and CAD modelling as it suits them. This approach is termed Alternative Mixed Media (AMM) and is currently the most popular among designers and design students. This study seeks to address a lack of evaluation with the AMM approach by investigating the impacts of switching between different design media on designers' cognition and creative design processes.

Literature about design activities in mixed media environments mainly focuses on design outcomes using SMM. There have been few AMM studies that explore the roles of sketching and CAD modelling and how switching behaviours impact on designers' cognition and creative design processes. This study compares two different approaches of interacting with sketching and CAD modelling (SMM versus AMM) to elucidate how switching behaviours impact on designers' cognition and creative design processes.

Many studies show that protocol analysis is effective in recording designers' reasoning during the design process. Research questions about whether switching behaviours impact on designers' cognition and creative design processes remain unanswered. Protocol analysis was used to facilitate controlled observations and experimental analyses to investigate the research

questions and objectives. The main study contains three parts: the SMM study, the AMM study, and SMM versus AMM study. The results of the SMM study with four participants show that dissatisfaction with sketches resulted in CAD modelling being used to support conceptual design. Being dissatisfied with sketches, the whole CAD design phase became uncertain. This played a key role driving designers to new solutions and involved considerable cognitive effort on evaluation.

The results of the AMM study with six participants show that both sketching and CAD modelling play a markedly similar role. A switching behaviour model was proposed containing eyes' switching, single switching and integrated switching. These behaviours appropriately supported designers in the design process. Concept-level switching behaviour can integrate two design media into one design medium. Concept-level switching behaviour has considerable potential to transform design processes into creative design processes.

The results of the SMM versus AMM study with eight participants show that there is no significant difference between sketching and CAD modelling. One of the difficulties experienced was that the think-aloud method used to collect data was unable to capture participants' thoughts about switches because each switch takes only a few milliseconds. Participants were subsequently interviewed about each switch and reminded about their design activities using video recordings. Their reflections were collected on completion of their design tasks. Six of the eight participants strongly believed that switching behaviour is essential to use the advantages of both media, and to use each one to counter the weaknesses of the other.

This research is a thesis by publication, comprising an introduction, literature review, methodology, discussion, conclusion, and seven publications. Paper One provides the framework and identifies a gap for a mixed media design study that developed as part of the overall study. Paper Two expands upon the literature reviewed in Paper One. It covers different types of design media research and focusses on switching behaviour in mixed media design environments. Paper Three builds upon the research design section described in Paper Two and reports the conduct of a pilot study. Paper Four expands on Paper Three to solidify the preliminary outcomes. Paper Five further explores Paper Four involving four designers to focus on the roles of design media using the SMM approach as part of a main study. Paper Five expands upon Paper Four involving six participants using the AMM approach to solidify the analysis of design activities as well as of switching behaviours as a part of the main study. Paper Seven expands upon Paper Five and Paper Six to solidify the main study outcomes involving eight participants using both SMM and AMM approaches. The outcomes are discussed in relation to two aspects: the roles of design media and designers' reflections.

This study used two approaches in this mixed media research: the SMM and AMM. The aim of this study is to investigate the impact of switching behaviours on designers’ cognition and creative design processes. The SMM approach was conducted as a baseline to compare participants’ design activities and their reflections. Based on the reflections, switching behaviours not only allowed for a more accurate testing of conceptual sketches but also facilitated the enhancement of designs. Switching behaviours were found to support designers by allowing them to: (i) make appropriate design decisions; (ii) enhance co-evolution; and (iii) provide a natural design workflow. Based on an analysis of design activities, switching behaviours supported designers’ perceptions, media and concept levels during their design activities.

Thesis structure

This thesis by publication delivers in three parts: thesis chapters, published papers and appendices.

Part I: Thesis chapters (C 1 ~ C 5)

Part II: Published papers (P 1 ~ P 7)

P 1. Shih, Y. T., Williams, A. & Gu, N. (2011). A method to investigate differences of sketching before and during CAD modelling design process. *Proceedings of the 2011 International Conference of the Association of Architecture Schools of Australia* (AASA), Geelong, Australia, pp. 308-318 (ISBN 978-0-9581925-5-2)

P 2. Shih, Y. T., Williams, A., Gu, N. & Lee, J. H. (2011). A switching coding scheme for exploring design cognition in mixed media design environments. *Proceedings of the 45th Conference of the Australian and New Zealand Architectural Science Association* (ANZAScA), Sydney, Australia, (ISBN 978-0-9581221-3-9)

P 3. Shih, Y. T., Sher, D. W. & Taylor, M. (2013). Using FBS ontology to analyse and compare designers' reasoning processes in SMM and AMM design environments: A pilot study with architectural designers. In M. A. Schnabel & J-Y Tsou (eds.), *Cutting Edge in Architectural Science: Proceedings of the 47th International Conference of the Architectural Science Association* (ASA), Hong Kong, pp. 123-132 (ISBN 978-0-9923835-0-3)

P 4. Shih, Y. T., Sher, D. W. & Taylor, M. (2015). Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers. *International Journal of Architectural Research*, *9*(3) (Scopus)

P 5. Shih, Y. T., Sher, D. W. & Taylor, M. (2017). The roles of design media for teaching architectural design. *Journal of Architectural and Planning Research* (SSCI) (under review)

P 6. Shih, Y. T., Sher, D. W. & Taylor, M. (2017). Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes. *Design Studies* (SCI) (In press)

P 7. Shih, Y. T., Sher, D. W. & Taylor, M. (2017). A comparison of designers' reflections of designing using sketching and CAD modelling. *Research in Engineering Design* (SCI) (with editor)

Part III: Appendices (A 1 ~ A 6)

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PART I

THIS PART INCLUDES FIVE CHAPTERS:

C 1. INTRODUCTION
C 2. LITERATURE REVIEW
C 3. RESEARCH METHODOLOGY
C 4. DATA AND DISCUSSION
C 5. CONCLUSION

Chapter 1: Introduction

This study concerns the roles design media play when used in different ways (e.g. linear approaches and integrated approaches) in the design process. Design media—including memos, computer-aided design (CAD) models and drawings—support and stimulate the design process and memory (Suwa & Tversky, 1997). Romer, Pache, Weißhahn, Lindemann, and Hacker (2001) found that sketching and CAD modelling are the most popular design media employed in design schools. It is widely recognised that the development of effective design support media depends upon perceptive insights into design cognition (Oxman, 2006; Suwa & Tversky, 1997). Thus research into cognitive activity is pivotal to empirical design studies, focusing on the different approaches of interacting with sketching and CAD modelling during design.

This study has investigated two different approaches to interactions between sketching and CAD modelling and how switching between the media impacts on designers' cognition and creative design processes. For this study, eight designers with at least two years of industry design experience were recruited. They were each asked to complete two different building design briefs using these approaches in a protocol study in which their activities were video recorded. The data collected included recordings of their design activities, reflections about these approaches and the ways they switched between the media. From the video recordings, a protocol analysis was conducted to examine the two sets of data. The first set was based on a think-aloud protocol (for the design activities). The second set of data came from participant interviews about their switching behaviours. Both sets were analysed using process-orientated (function-behaviour-structure) and content-orientated (perception, media and concept) coding schemes. Moreover, designers' reflections were transcribed and categorised as either positive or negative. Additionally, their reflections were also categorised according to how switching behaviours impacted on their design cognition as well as the design process.

This thesis by publication is separated into three parts. Part I is the research framework, Part II is the published papers, and Part III presents supporting appendices. Part I focusses on literature and background to the study, as well as the research methodology. Central to this part is an identification of how this study has utilised past research to advance new experiments and analyses of designers' cognitive behaviours. Outcomes of this study are discussed and summarised in the conclusion. Part II provides a series of papers that are organised to reveal both the research process and their outcomes. They range from initial findings on the use of mixed media, and the perceived advantages of AMM processes, through to the way designers interact with various media during the design phase. Supporting appendices in Part III include ethics approvals, participants' consent forms, design briefs, design outcomes, and coding.

1.1 Motivation

Designers' interactions with design media have shifted from individual design media to multiple design media to improve design activities and outcomes. In empirical studies conducted by Chen (2007) and Ibrahim and Rahimian (2011), designers were asked to initially use traditional sketching before shifting to CAD modelling. For the purpose of the study reported in this thesis, this use of mixed media, in which a single shift between media occurs, is defined as Sequential Mixed Media (SMM). Researchers (Sachse, Leinert, & Hacker, 2001) found, however, that designers preferred to interact freely between media, alternating between sketching and CAD modelling as it suited them. This aligns with Do's concept of the 'right tool-right time' (Do, 2005, p. 396). Do argues that design environments need to provide the tools that a designer needs at that time; rather than being limited to specific design media. This approach is termed Alternative Mixed Media (AMM) and is currently popular among designers and design students.

When Ibrahim and Rahimian (2011) compared traditional sketching, CAD modelling and mixed media to assess their influence on design activities, they found that a mixed media design environment improved the quality of the ultimate design product. The mixed environment, comprising sketching and CAD modelling, was found to be more effective than a single design medium (Ibrahim & Rahimian, 2011; Sachse et al., 2001). This reflects designers' preferences and consequently the most popular design media employed by contemporary design schools. Chen (2007) found that creativity is stimulated as designers improved the ideas they sketched by subsequently developing those ideas in digital design environments. A creative process involves redefining problems and developing solutions called co-evolution (Maher & Poon, 1996). This model fits Dorst and Cross's (2001) design creativity study in that they argue that a creative design process is not a matter of first defining a problem and then searching for a satisfactory solution; rather a creative design process involves the interchange of information between problems and solutions. The AMM approach allows designers to interact freely between sketching and CAD modelling for 'co-evolution' during designing. The AMM approach may involve a high frequency of switching between media corresponding to the interchange of information between problems and solutions. These iterations during designing can be viewed as a creative design process.

Most of the research about design activities in mixed media design environments is based on the SMM approach (Chen, 2007; Ibrahim & Rahimian, 2011). However, there is little empirical evidence about design activities using the AMM approach (Shih, Sher, & Taylor, 2015). Questions about the differences between the SMM and AMM approaches in terms of design processes and designers' reflections, and whether switching behaviour impacts on designers' cognition, remain unanswered. To address these issues, a protocol study was conducted in which eight professional architectural designers were asked to complete different building design briefs using the two approaches. Protocol analysis and two types of coding schemes were adopted and developed to examine participants' design activities and switching behaviours. Moreover, designers' reflections about the two approaches were collected and analysed to identify the impact of their switching behaviours.

1.2 Research Aim and Objectives

1.2.1 Research aim

The aim of this study is to investigate the impact of switching behaviours on designers' cognition and creative design processes.

1.2.1.1 Research objectives

To achieve this aim, the following objectives were identified:

1. To develop a framework of mixed media that involves switches between design media;
2. To conduct a pilot study;
3. To explore the factors that triggered change in the roles of CAD modelling in the SMM study;
4. To identify the roles of sketching and CAD modelling in the AMM study;
5. To develop definitions for different types of switching behaviours in the AMM study;
6. To identify which type of switching behaviours support design cognition as well as the creative design process in the AMM study;
7. To determine similarities and differences in the roles of sketching and CAD modelling using the SMM and AMM approaches; and
8. To compare the advantages and disadvantages of the SMM and AMM approaches, based on designers' reflections.

Table 1.1 shows the mapping between these research objectives and the seven papers presented in this thesis by publication. The relationships among these papers and how they contribute to this study are discussed in the following section.

Table 1.1 Matrix of research objectives with papers.

	Paper 1	Paper 2	Paper 3	Paper 4	Paper 5	Paper 6	Paper 7
Objective 1	✓	✓					
Objective 2			✓	✓			
Objective 3					✓		
Objective 4						✓	
Objective 5						✓	
Objective 6						✓	
Objective 7							✓
Objective 8							✓

1.2.2 Research design overview

The aim of this study is to investigate the impact of switching behaviours on designers' cognition and creative design process by comparing their design activities and reflections using the SMM and AMM approaches. The research method adopted for the study is protocol analysis and the reasons for the selection of this method are discussed in Chapter 3. This study comprises firstly a pilot study, followed by a more comprehensive (main) study in Chapter 4. The design tasks involved recruiting two participants for the pilot study and then eight for the main study. All participants needed to have at least two years professional design experience, be competent at both sketching and CAD modelling, and have a Bachelor of Architectural Design degree. The pilot study had two purposes:

1. To explore whether the experimental design was effective in producing potential outcomes; and
2. To test whether meaningful patterns emerge by applying the developed coding scheme.

Upon completion of the pilot study and based on the preliminary results, the experimental design and developed coding schemes were revised. In the study, the participant randomly completed the following three architectural design briefs using the SMM and AMM approaches:

1. A two-floor architectural office design;

2. A two-floor art gallery design; and
3. A two-floor dream apartment design.

All participations were required to think-aloud, verbally describing their activities during the design sessions. This was followed by an interview about designers' reflections on SMM and AMM. Finally, the study analysed switching behaviours to define how the switching behaviours may impact on design cognition and creative design processes.

1.3 The Published Papers and their Contribution to the Thesis

1.3.1 List of published papers

This section lists seven papers and then summarises their contents. The candidate was the primary author of these peer-review papers.

- Paper One (P 1): Shih, Y. T., Williams, A. & Gu, N. (2011). A method to investigate differences of sketching before and during CAD modelling design process. *Proceedings of the 2011 International Conference of the Association of Architecture Schools of Australia* (AASA), Geelong, Australia, pp. 308-318 (ISBN 978-0-9581925-5-2)
- Paper Two (P 2): Shih, Y. T., Williams, A., Gu, N. & Lee, J. H. (2011). A switching coding scheme for exploring design cognition in mixed media design environments. *Proceedings of the 45th Conference of the Australian and New Zealand Architectural Science Association* (ANZAScA), Sydney, Australia, (ISBN 978-0-9581221-3-9)
- Paper Three (P 3) Shih, Y. T., Sher, D. W., & Taylor, M. (2013). Using FBS ontology to analyse and compare designers' reasoning processes in SMM and AMM design environments: A pilot study with architectural designers. In M. A. Schnabel & J-Y Tsou (eds.), *Cutting Edge in Architectural Science: Proceedings of the 47th International Conference of the Architectural Science Association* (ASA), Hong Kong, pp. 123-132 (ISBN 978-0-9923835-0-3)
- Paper Four (P 4) Shih, Y. T., Sher, D. W., & Taylor, M. (2015). Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers. *International Journal of Architectural Research*, *9*(3) (Scopus)

- Paper Five (P 5) Shih, Y. T., Sher, D. W., & Taylor, M. (2017). The roles of design media for teaching architectural design. *Journal of Architectural and Planning Research (SSCI)* (under review)
- Paper Six (P 6) Shih, Y. T., Sher, D. W., & Taylor, M. (2017). Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes. *Design Studies (SCI)* (In press)
- Paper Seven (P 7) Shih, Y. T., Sher, D. W., & Taylor, M. (2017). A comparison of designers' reflections of designing using sketching and CAD modelling. *Research in Engineering Design (SCI)* (with editor)

1.3.2 Content summary of included papers

This section summarises the papers listed in section 1.3.1. It discusses how each paper relates to other papers and contributes towards addressing the research questions identified in section 1.2.

P 1: A method to investigate differences of sketching before and during CAD modelling design process. (Shih, Williams, & Gu, 2011)

This paper provides the framework for a mixed media design study that developed as part of the overall study. It emerged from the realisation that design activity is increasingly being influenced by the introduction of new technologies and questioned how these technologies were being incorporated in the design process. Invariably these technologies extend beyond mere support of the design process and may influence the process itself. This influence may be an enhancement but it may also limit or constrain design. It is therefore important to have an understanding of the impact of the new technologies on design and to extend this understanding to how and when in the design process they would be most effective.

This paper identifies a gap in identifying the impact of mixed media design environments that integrate digital technologies (i.e. CAD modelling) with traditional modes of design (i.e. sketching). Existing understanding indicates that there is the potential to enhance the utilisation of these design media in an integrated approach rather than simply sketching preceding design documentation using CAD. The paper proposes that the application of protocol analysis provides an appreciation of how these two modes of design environments may be better utilised to support the design process. This study sought an optimal approach to facilitate architectural design processes.

P 2: A switching coding scheme for exploring design cognition in mixed media design environments. (Shih, Williams, Gu, & Lee, 2011)

This paper expands upon the literature reviewed in Paper One. It covers different types of design media research and focusses on switching behaviour in mixed media design environments. The paper then discusses a study involving the mixing of sketching and CAD modelling design environments and reviews types of research methods based on relevant design cognitive research. It further solidifies the two types of coding schemes for analysing the design process and switching behaviours. In summary, the paper precedes the main research instigation, and underpins the need for the study and an approach to explore the application of traditional and current technology to support design processes.

P 3: Using FBS ontology to analyse and compare designers' reasoning processes in SMM and AMM design environments: A pilot study with architectural designers. (Shih, Sher, & Taylor, 2013)

This paper builds upon the research design section described in Paper Two. It reports the conduct of a pilot study to gather information about design cognition to analyse designers' behaviours while they are working in mixed media design environments (SMM and AMM). The main deliverables of this paper include:

- Exploring whether the experimental design achieves the purposes of the project and satisfies the research requirements; and
- Testing whether meaningful patterns emerge through the application of the adopted coding schemes.

P 4: Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers. (Shih, Sher, & Taylor, 2015)

This paper expands on Paper Three to solidify the preliminary outcomes. The paper delivers the following:

- The results show that the designers switched many times between sketching and CAD modelling during AMM design processes.
- Two participants' switches are effective in influencing design processes because the switches integrate both sketching and CAD modelling as one design medium.

In summary, most of the concepts and analyses developed in subsequent papers are based on the research method and research design introduced in this paper.

P 5: The roles of design media for teaching architectural design. (Shih, Sher, & Taylor, 2017)

This paper further explores Paper Four involving four designers to focus on the roles of design media using the SMM approach as part of a main study. The main deliverables of this paper include:

- Dissatisfaction with prior sketches resulted in CAD modelling being used to support conceptual design.
- Being dissatisfied with sketches, the whole CAD design phase became uncertain. This played a key role driving designers to develop new solutions involving considerable cognitive effort.
- Developed a model for the phenomenon of CAD modelling used to support conceptual design or design documentation in mixed media design environments.

In summary, the main contribution of this paper is to explore a triggering factor for enhancing the CAD phase using the SMM approach. Due to the increased complexity of design tasks, different technical design media were used to facilitate design processes.

However, each design medium has its advantages and disadvantages. Thus an optimal solution may not be achieved after the use of one design media. This means that subsequent design sessions (e.g. CAD modelling) need to support designers to refine their prior designs (e.g. in sketching session) by evaluating alternatives.

P 6: Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes. (Shih, Sher, & Taylor, 2017)

This paper expands upon Paper Four involving six participants using the AMM approach to solidify the analysis of design activities as well as of switching behaviours as a part of the main study. The paper delivered the following:

- Both sketching and CAD modelling played a markedly similar role in mixed media design environments.
- Developed definitions for three types of switching behaviours: eyes' switching, single switching and integrated switching.
- These switching behaviours supported designers in their perception, media and concept levels in the design process.
- Concept-level switching behaviour can merge two design media into a single design media.
- The concept-level switching behaviour has considerable potential to transform the design process into a creative one.

P 7: A comparison of designers' reflections of designing using sketching and CAD modelling. (Shih, Sher, & Taylor, 2017)

This paper expands upon Papers Five and Six to solidify the main study outcomes involving eight participants using both SMM and AMM approaches. The outcomes are discussed in relation to two aspects: the roles of design media and designers' reflections. The comparisons of design activities indicate that there are more similarities than differences in how designers interact with sketches and CAD modelling. Both SMM and AMM media relate to a solution-focused style, when the percentages of the FBS design issues are compared. Sketching was shown to assist designers in identifying a problem, whereas CAD modelling provided a means to resolve the problem and offered solutions.

On the other hand, the comparisons of designers' reflections indicated that there were more differences than there were similarities after using the two approaches. Although a couple of designers were satisfied with the SMM approach, most felt that it was difficult to complete the tasks without switching between media. All participants had the same opinion after using the AMM approach. Each design medium was seen to have its own advantages and disadvantages. More importantly, the role of switching behaviour is to make use of the advantages from both media, and to use each one to counter the weaknesses of the other. This allows a designer to be fast and accurate, which supports Ibrahim and Rahimian's (2011) and Sachse et al.'s (2001) findings of using fewer steps to complete design works.

1.4 Significance of the Study

The development of the AMM approach provides a new perspective, involving three types of switching behaviours in mixed media design environments. A comprehensive understanding of designers' cognitive activities using AMM can be classified into two aspects. Firstly, it provides an understanding of the similarities and differences in design activities between SMM and AMM. Secondly, it investigates the impact of switching behaviours on design cognition.

Figure 1.1 provides an example of design activities using the AMM approach containing three types of design behaviours. From empirical evidence the period of a creative design was identified in the AMM design process.

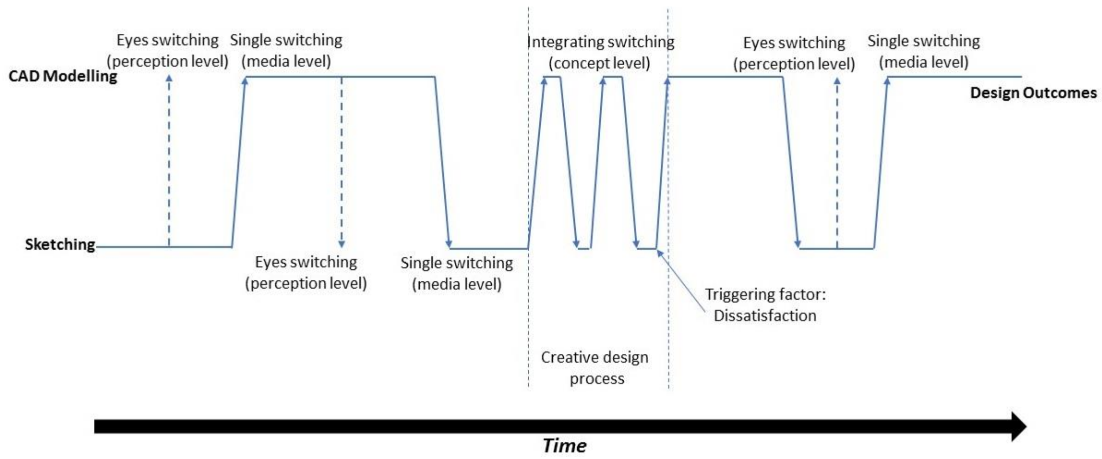


Figure 1.1. An example of design activities using the AMM design approach.

The definition of these switching behaviours is explored below:

- *Eyes' switching* refers solely to where designers *look*. For instance, during the CAD modelling process, a designer may map the current CAD model with its sketched layout to enhance their visual thinking.
- *Single switching* refers to where designers *look and execute* actions. They may switch from sketching to CAD modelling or from CAD modelling to sketching to progress their work. The strengths and weaknesses of these media are complementary as, for example, a designer may finish ground-floor CAD models and then sketch ideas for the first-floor layout. The main difference between *eyes' switching* and *single switching* is that single switching involves moving to another design media to continue design work, whilst eyes' switching involves using the same design media by retrieving visual information from the other media.
- *Integrating switching* refers to where designers *look and execute actions involving multiple switches between the media*, focusing on a particular issue. For example, this may be where the designer of a stair designs for circulation between two storeys through the co-evolution problems and solutions.

Based on the empirical evidence, these types of switching behaviours supported designers in the perception, media and concept levels during designing. Moreover, dissatisfaction was identified as a triggering factor for switching. The results of this study show that concept level switching behaviour can integrate two design media into one. This level of switching behaviour has considerable potential to transform a design process into a creative design process, which supports Chen's (2007) findings of using conventional and digital media simultaneously. This involves iterative switches to explore problems either in the sketching environment or in the CAD modelling environment. Solutions may then be refined using other design environments. Similarly, this study should inform further discourse on how designers intuitively interact with mixed media, and how sketching and CAD modelling integrate into one design media to enhance the three levels of designers' cognition in the design process.

1.5 Research Scope and Limitations

The scope of this study was to adapt Do's concept of the 'right tool-right time' (Do, 2005, p. 396) in mixed media design environments. The title of Paper 6 'Using suitable design media appropriately' refers to this concept. The SMM approach was used as the baseline to compare design activities with the AMM approach. This enabled the impact of switching behaviours to be explored. In order to achieve the aim of this research, the protocol analysis methodology was selected to investigate the mixed media design processes. The outcomes of design solutions/layouts were not analysed because the experimental period for each design session was limited.

The limitations of the research method are as follows:

- The limitation of protocol analysis — This method has both advantages and limitations. The advantage is that it provides rich raw data (including designers' verbalisation, gestures and drawings) and provides accurate information regarding decision-making processes due to the concurrent nature of data collection (Guyton-Simmons & Ehrmin, 1994). The limitation is that the unstructured raw data needs extensive time for analysis. This is why the reliability of some protocol studies has been questioned as the results are based on a small number of participants. This study involved eight designers and produced a relatively large amount of cognitive data. Each designer was asked to complete two different architectural design briefs using the SMM and AMM approaches. Moreover, the designers provided their reflections after using these approaches as well as their reasons for each switching behaviour. These were video recorded. Analysing these data produced comprehensive research outcomes.

- The limitation of think aloud — The advantages of concurrent verbalisation fit the aim of this research because this process focuses on analysing designers' cognitive actions rather than subjective self-reports (Salman, Laing, & Conniff, 2014). Concurrent verbalisation was selected as a suitable and robust approach for this study. Appropriate design protocols for this study included recording all forms of each designer's overt behaviours, such as their verbalisation, sketching, CAD modelling and switching between media. However, the think-aloud method was limited. As each switching behaviour took only a millisecond, participants did not have time to verbalise their reasons for switching. Therefore, on completion of the mixed media sessions, participants were asked to review videos of their design actions and explain the reasons for their switches.

The following chapter provides a review of the literature on different design environments, and the cognitive models for the design process. These illustrate the theoretical backgrounds and highlight the need for the proposed research. Additionally, the literature review indicates the research gap and drives the research questions. It also updates the literature reviews included in published papers (P 1~ P 7) and highlights salient points.

Chapter 2: Literature Review

This chapter reviews the design studies related to design media and the switching behaviours in designing to provide a context to the study of the impact of switching behaviours. The co-evolution between problem space and solution space as a creative design process has been recognised as one of the key issues in design studies research (Maher, Poon, & Boulanger, 1996; Dorst & Cross, 2001; Raymond & Scott, 2012). There are several design studies on the use of mixed design media compared to individual design media during the design process (Chen, 2007; Ibrahim & Rahimian, 2011). A number of themes can be identified in the literature; however, three linked themes are important: (i) design activity involves design media, (ii) design activity involves a creative design process; and (iii) design activity involves the most suitable approach of using design media.

Additionally, the main goals of Paper One (P1) and Paper Two (P2) were to build a framework of mixed media design research based on the synthesis of Chapters 2 and 3. This chapter identifies the knowledge gap of the impact of switching behaviours on designers' cognition as well as a creative design process. Firstly, design studies research using different media is explored. Secondly, the role of uncertainty during designing is reviewed. The third section investigates the characteristics of the creative design process, leading to a coding scheme for analysing switching behaviours. Finally, in the last section different types of switching behaviours are introduced.

2.1 Design Media Research

External aids, such as sketches and models, are extremely influential during the early stages of task clarification and conceptual design; these aids create design environments that are supportive of idea exploration and visual representation (Oxman, 2000, 2006). External aids encourage detailed problem finding while simultaneously reducing the designers' cognitive load. According to a survey of 106 designers conducted by Romer et al. (2001), the two most frequently used design media in the design industry and design schools are sketching and CAD modelling. Respondents were asked 'how often do you use…?' and 'what do you use…for?' in terms of sketches, physical models and CAD. Figure 2.1 shows the frequency of the use of external representations. Figure 2.2 shows that sketches are used frequently for solution development, supporting memory and communication while CAD is used primarily for solution development, testing solutions, documentation, and supporting communication.

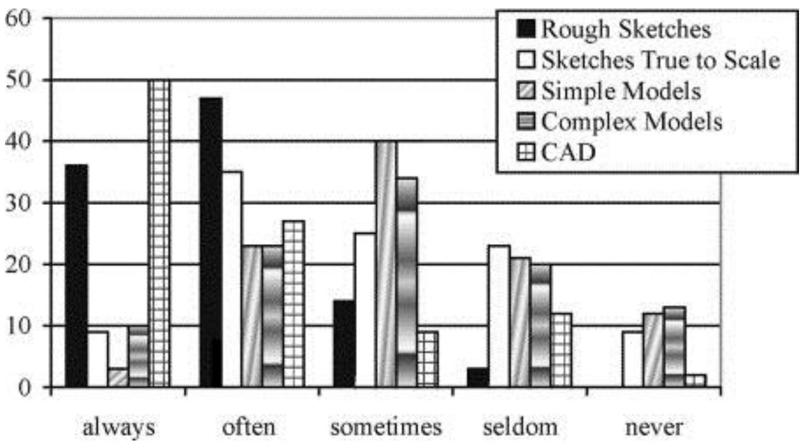


Figure 2.1. Frequency of use of external representations in percentages (Romer et al., 2001).

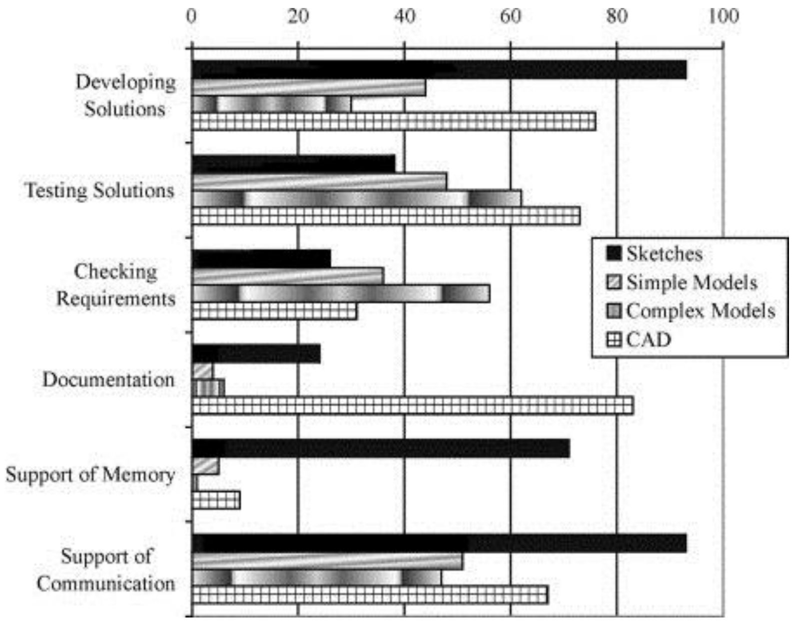


Figure 2.2. Purposes of using external representations in percentages (Romer et al., 2001).

2.1.1 Sketching design research

Sketching plays a pivotal role in the initiation and development of creative ideas during the early design phase. Designers rely on it to support and accentuate the visual reasoning necessary to explore the spatial relationship between diagrams. The design problem space evolves from an ill-defined problem to the identification and resolution of creative ideas when designers interact with sketches (Purcell & Gero, 1998).

Sketching is used to generate, test and record a designer's creative and conceptual thinking about a design. Yamamoto, Nakakoji and Takada (2000) describe sketching as a hands-on representation, 'with which the designer can easily perform trial-and-error and examine the whole as well as parts of the whole, allowing the designers to represent any levels of preciseness as they like' (Yamamoto et al., 2000, p. 376). Ullman, Wood and Craig (1990) studied the influence of early conceptual sketches on the mechanical design process. They concluded that drawings served six primary purposes in design problem solving:

1. to store conceptual ideas;
2. to provide visual communication between designers;
3. to simulate design;
4. as an analytical tool;
5. as a standard against which completion can be measured; and
6. as an extended memory.

The sketching process underpins the wide range of cognitive activities necessary to produce design solutions. Studies conducted by Suwa, Purcell and Gero (1999) show that designers' first access conceptual knowledge from memory before undertaking the decision-making process. For example, designers frequently draw shapes, lines and/or arrows on paper and ask themselves questions like 'where does the sunlight come in?' and 'what if I put the garage in the southwest corner?' Consequently, sketching is an important aid to the stimulation of visual and spatial relationships in the environment. Therefore, it is difficult to achieve a design goal without using an external aid such as drawing.

In addition, sketching offers more to designers than simply a convenient way of solving design problems. The actual process of sketching helps designers to absorb design ideas (Lawson, 2004, 2006). As an idea is conveyed from eye to mind and mind to hand, designers deepen their understanding of the objects and places with which they are dealing. As Gero and Tang (2001) point out, pencil and paper drawings are a way of externalising mental images and, in so doing, increase knowledge and understanding about the nature of these images. It is not surprising then, that architectural design relies upon the use of pencil and paper media during the conceptual development phase. From the foundation of a simple sketch, doodle and/or diagram, designers are able to develop their ideas graphically using freehand soft line sketching on tracing paper. The process of sketching during the development of a design involves a form of creative play in which new forms are discovered, adapted and combined with already known shapes and structures. Thus, sketching does more than communicate ideas; it is an aid to visualisation, conceptualisation, and an understanding of the forms designers are working on (Do & Gross, 1995).

Research on sketching also identifies cognitive issues that are important to the design context. Sketching is an easy method of storing designers' conceptual ideas so that they can be revisited (Ullman et al., 1990). When revisiting sketches, a designer may explore new concepts behind the original idea. 'Seeing-as' and 'seeing-that' modes were observed amongst architectural students when they generated ambiguous sketching (Goldschmidt, 1990, 1991). Similarly, Schon and Wiggins (1992) argued that sketching, which is greatly dependent upon seeing according to the 'seeing-moving-seeing' model, allows designers to engage in a conversation with design media focusing on their eye movements between drawings and pencil/paper. These conversations result in representations of design solutions that are open to a variety of interpretations and can lead to different streams of sequential decisions (Scrivener & Clark, 1994). Schön's (1983, 1992) concept infers that a reflective conversation is one in which a designer is 'seeing what is there, drawing in relation to it, seeing what is drawn' and thus progresses the design. This iterative method of testing ideas and informing the design phase through the use of images directs and aids a designers' decision making.

The important contribution of freehand sketching to the design process deserves attention. In the initial phase of the sketching process, designers brainstorm as many ideas as possible. Freehand sketching is central to this process as raw sketches can be easily generated, revised, refined and consolidated in conjunction with the development of ideas. Consequently, sketches act as a conceptual tool for designers, supporting and stimulating creativity (Robbins, 1994; Schön, 1992; Goldschmidt, 1995). Suwa and Tversky (2001) note that professional designers use sketching to generate new ideas, rather than simply to express current ideas. The simple process of re-examining old sketches, one's own and others' can lead to unexpected discoveries that generate new ideas.

Although traditional sketching methods are low-cost, 2D sketches may not convey ideas about complicated 3D objects. For example, sketches are imprecise when multiple 2D views are used to produce a 3D perspective. In a CAD modelling design environment, 3D graphics (e.g. different angles of perspective views) can be employed to generate and manipulate 3D geometry (Oxman, 2006). CAD modelling can be meaningfully used to support problem solving in design processes. Conventional approaches involve sketching as a means of representing basic conventions, but these are inadequate for solving complicated problems (Lin, 2001). Furthermore, the increasing globalisation of design projects has complicated design processes, rendering conventional sketching tools largely inadequate. Consequently, CAD modelling is increasingly being used in complex projects because it provides the additional benefit of digital representation and communication for future analyses and process integration.

2.1.2 CAD modelling design research

In recent years CAD has emerged as a design tool that is capable of developing conceptual designs (Salman, Laing, & Conniff, 2014). The expressive and geometric power of CAD modelling has increased to such an extent that it can be solely used from beginning to end to achieve design goals. A CAD model can be drawn once and then viewed and plotted from any angle; it holds mathematical information that can be used in engineering analysis; and it can be shaded, rendered and assigned various materials for visualisation (Reffat, 2002). Since its inception, a large amount of research has focused on the CAD modelling design environment. Three important characteristics of this environment include:

1. Digital information can be transformed into eye tracking algorithms that allow users to interact with a computer in terms of understanding users' inputs;
2. The graphic image of CAD models can be printed; and
3. The data of 3D models can be transferred into other design stages (Mitchell, 1998; Ho, 2006).

CAD modelling has progressed to a level where it is adequate to communicate design expressions representing early stage design ideas right through to detailed drawings (Szalapaj, 2001). CAD modelling not only simplifies the design process for complex designs and improves communication between all parties involved in the process, but also hastens the design process and reduces costs (Lin, 2003). Digital media have the potential to enhance design cognition, intuition, and creativity (Hanna & Barber, 2001) because they can be used to continually develop and refine a shape without the need to delete a previous shape. CAD modelling therefore gives designers an alternative, realistic way to think about the design (Madrazo, 1999). The use of CAD modelling during the early design process has several advantages (van Elsas & Vergeest, 1998):

1. It can improve the quality of conceptual design;
2. It allows for faster generation of design alternatives;

3. It provides a platform to enhance communication and evaluation of these design alternatives; and

4. It can be used to avoid costly errors, as early design decisions can have a marked impact on the final cost of the design.

Collier and Fischer (1995) found that 2D graphic and 3D modelling when used to represent buildings may not generate the same responses from subjects as real buildings. Figure 2.3 showed that designers draw 2D representations of their mind's 3D image. Everyone involved in this design has to see the 2D drawings to build his own mental 3D image; this could lead to the creation of incomplete 3D images. It means that 2D representations may be inadequate to convey ideas, even just a combination of two simple objects.

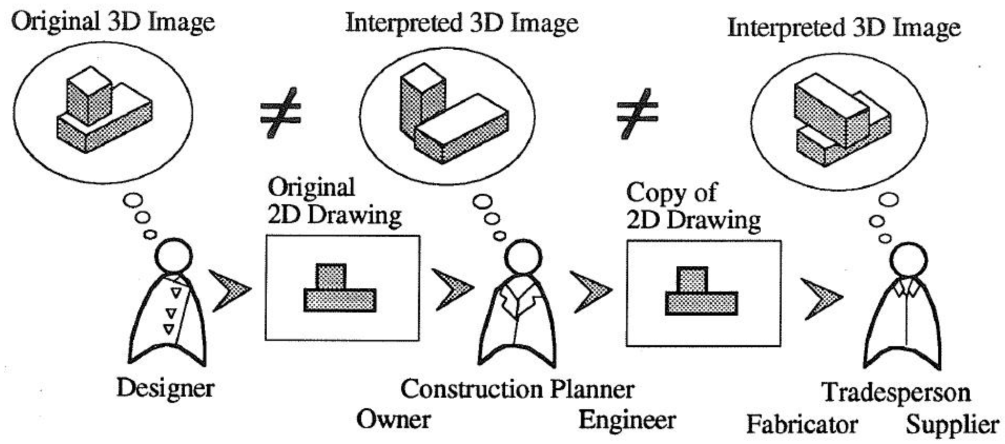


Figure 2.3. 2D drawings produce different 3D models (Collier & Fischer, 1995).

Collier and Fischer (1995) noted, however, that 3D models were more effective in evoking a more accurate response to the real building than plan sketching. Just as for a physical model, the CAD model gives everyone the same view of the final 3D image. The final image is articulated accurately in CAD modelling rather than in abstraction as is the case with 2D drawings. Figure 2.4 demonstrates that everyone involved in a design is able to perceive the same idea by viewing the 3D models.

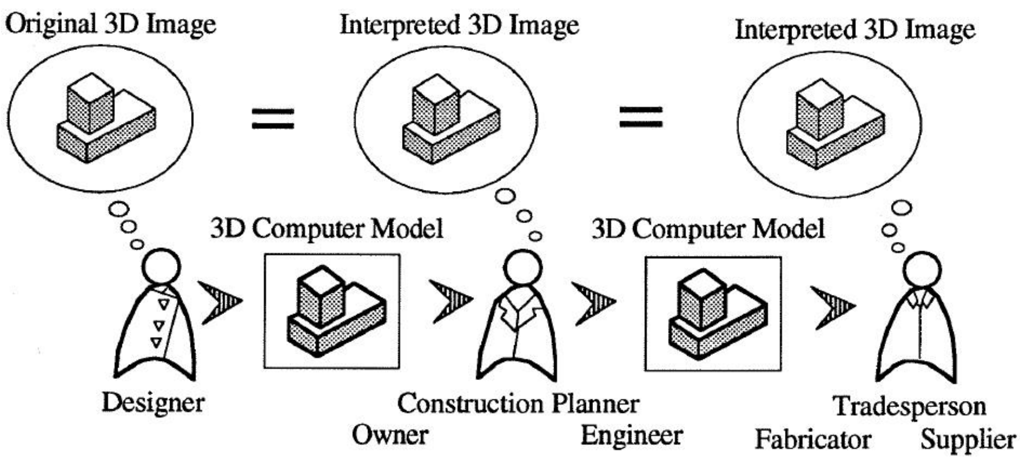


Figure 2.4. CAD modelling articulate better views for everyone (Collier & Fischer, 1995).

More recently, CAD modelling has proved to be an effective Architecture Engineering and Construction (AEC) practice. For example, designers and clients use CAD models to review and evaluate building designs before construction (Bouchlaghem, Shang, Whyte, & Ganah, 2005). Reffat (2002) stated that these models provide designers with opportunities to make substantial changes at a reasonable cost. Furthermore, engineers use CAD models to evaluate structural alternatives and industry professionals use them to estimate costs and plan cost-effective construction sequences. These processes frequently unearth design conflicts that would otherwise result in expensive construction defects.

For existing buildings it is often desirable to use CAD models to analyse the energy properties of light and heat, to explore how a potential fire could spread, to explore potential changes in a building, and to increase the possible uses of existing building spaces (Eastman, Teicholz, Sacks, & Liston, 2011). Moreover, the accurate visualisations made possible with CAD modelling may help designers to alter and refine their design thinking (Salman, Laing, & Conniff, 2014). Won's comparison of designers' visual thinking when moving between sketching and CAD modelling environments found that CAD modelling assisted designers in shifting between overall design and detailed design, although both design media supported design activities (Won, 2001). Table 2.1 summarises the challenges and benefits of sketching and CAD modelling during the conceptual design phase (Rahimian, Ibrahim, & Jaafar, 2008).

Table 2.1. Challenges and benefits of sketching and CAD modelling (Rahimian, et al., 2008).

	Benefits	Challenges
Sketching	1. Flexibility in ideation due to tangible interface	1. Less capability to shift from micro to macro level and vice versa
	2. Easy to use	2. More tacit information flow walkthrough
	3. Easy to learn	3. Fewer visualisation details
	4. Easy to change/reform design alternatives	4. Fragile models and documents for editing or reviewing
	5. Able to use different drawing scales and possible to trade off between accuracy and clearness	5. Difficult to add and control details of design alternatives due to visualisation problems
	6. Maintains design ideas during design process Possible to review and compare all documents	6. Difficult to transition to other design stages because of format
CAD modelling	1. Easier to prepare documentation	1. Difficulty of obtaining ability to use
	2. Capability for zooming and panning for easier walkthrough	2. Arduousness of I/O devices which interrupt creativity of designers
	3. Capability for temporally omitting an object or group of objects	3. Losing consistency of spaces due to lack of ability to control ubiquitous design idea in an artistic way
	4. Capability for undoing undesired changes	
	5. More detailed, realistic and elaborate perspectives due to high capability of visualisation	

2.1.3 Mixed media design research

In recent years research has shifted from single design media to the influence of mixed media on cognitive activities during design. Evidence for the use of mixed media comes from

Sachse et al. (2001) who surveyed more than 100 expert designers who used sketching prior to and concurrently with CAD modelling. Their study identified three positive outcomes of this approach: better solutions, faster task completion, and fewer processing steps to develop CAD models. These results are supported by Chen (2007), who studied design creativity in individuals using conventional and digital media simultaneously. Chen's results showed that, as designers switch from sketching to digital tools, design creativity is stimulated because switching behaviour causes them to re-think previous ideas. This results in improvements to the quality of their design soultions.

Ibrahim and Rahimian (2011) argued that the CAD software available at the time did not facilitate the intuitive aspects of conceptual design and they therefore investigated mixed media. They conducted a protocol study of architectural students in three discrete design environments (mixed media, sketching and CAD modelling) and found mixed media to be the most effective external representation aid because it generated higher quality solutions than either CAD modelling or sketching. However, this study focused on evaluating design solutions from different design media as opposed to design processes. Different approaches of using design media during designing may influence the roles of design media. The roles of sketching and CAD modelling in mixed media design environments remains unclear as a result.

In the mixed media studies reviewed for this chapter (Chen, 2007; Ibrahim & Rahimian, 2011), participants followed a linear process of sketching prior to using CAD modelling. However, this does not imply that there is only one solution, since in reality many possible solutions are generated when designing to meet specific requirements. This process involves redefining problems and developing solutions, called co-evolution by Maher, Poon and Boulanger (Maher, Poon, & Boulanger, 1996) (Figure 2.5).

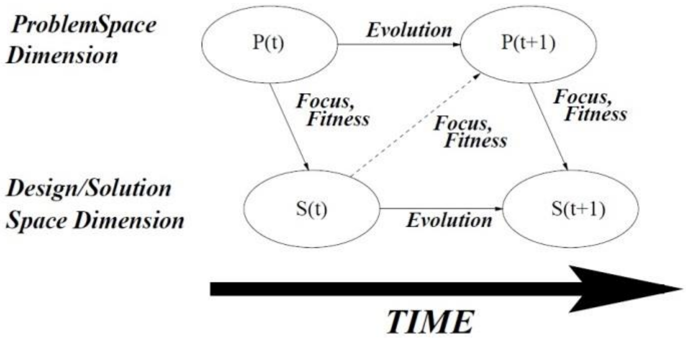


Figure 2.5. The co-evolution design model (Maher, Poon, & Boulanger, 1996).

The model illustrated in Figure 2.5 fits with Dorst and Cross's design creativity study (Dorst & Cross, 2001) in that they argue that creative design is not a matter of first defining a problem and then searching for a satisfactory solution. Creative design is a matter of the interchange of information between problems and solutions. Moreover, based on Table 2.1, the benefits and challenges of sketching and CAD modelling have a complementary relationship. For example, sketching has weak visualisation attributes whilst CAD modelling provides more detailed, realistic and elaborate perspectives. In contrast, sketches are easy to change and/or allow alternate designs to be developed, while CAD modelling can interrupt designers' creativity due to the often restrictive nature of input/output devices. Therefore, design media should fit designers' needs as per Do's concept of the 'right tool-right time' (Do, 2005, p. 396). The next section introduces why uncertainty plays an important factor in the early design stage.

2.2 Uncertainty During Designing

Providing a solution that effectively meets the requirements of a design brief is a designer's ultimate goal. Having a full understanding of the processes that lead to creative designs is of great interest to academics, designers and design researchers. In earlier descriptions of creative engineering design Buhl (1960) described design as a linear sequence involving the following steps: (1) preparation, (2) analysis, (3) synthesis, (4) evaluation, and (5) presentation. Similarly, a model describes creative approaches to a problem-solving activity as a linear sequence of: (1) framing a problem, (2) exploring data, (3) generating ideas, (4) developing solutions, and (5) appraising tasks (Isaksen, Dorval, & Treffinger, 1994).

The development of creative design processes is thus traditionally viewed as a sequence of activities involving the formulation of a problem, leading to the synthesis of solutions (Maher & Poon, 1996). However, design problems are often ill defined (Simon, 1983), meaning there is no definitive formulation of the design outcomes. Creative designers thus constantly generate design alternatives to redefine uncertainties. In practice, a designer develops and redefines both the formulation of a problem and his or her ideas for solutions, iterating between the design processes, the design requirements and the final outcomes.

An alternative to Isaksen et al.'s model is Gero's function-behaviour-structure (FBS) framework developed in 1990 (Gero, 1990) and enhanced over the last two decades. The process represented by the FBS model shows the transformation of design requirements into a design artefact. This model contains six design issues and eight design processes that describe all designed artefacts, irrespective of the specific design discipline. Gero and Kanengiesser (2014) proposed the six design issues begin with the goal of designing being to transform a set of requirements (R) into a set of design descriptions (D). The function (F) of a designed object is defined as its purpose (or teleology). The behaviour (B) of that object is how it achieves its functions and is either derived (Bs) or expected (Be) from the structure. The structure (S) comprises the elements of an object and their relationships. A design description is never transformed directly from the function but undergoes a series of design processes related to the FBS design issues (Figure 2.6).

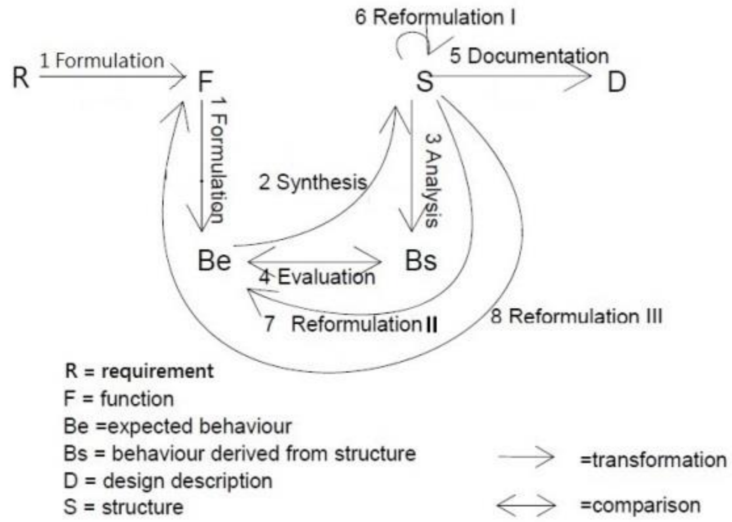


Figure 2.6. FBS design model (Gero & Kanengiesser, 2014).

These eight design processes include: a formulation (F→Be) which transforms functions into a set of expected behaviours; a synthesis (Be→S), wherein a structure is proposed that is likely to exhibit the expected behaviour; an analysis (S→Bs) of the structure which produces its derived behaviour; an evaluation process (Be⇆Bs) which acts between the expected behaviour and the behaviour derived from the structure; and documentation (S→D), which produces the design description (Gero & Kannengiesser, 2014). Depending on the structure, there are three types of reformulation, where new variables are introduced: reformulation of structure (S→S), reformulation of expected behaviour (S→Be), and reformulation of function (S →F). The primary advantage of the FBS coding scheme is that it clearly shows the relationships between the eight design processes and the six design issues. The FBS coding scheme has been used as a uniform framework to represent and classify design processes in numerous studies (Tang, Lee, & Gero, 2011; Gero, Jiang, & Williams, 2012; Williams, Lee, Gero, & Paretti, 2013; Kan & Gero, 2009; Gero, Kan, & Pourmohamadi, 2011). Therefore, the FBS coding scheme is a proven approach and has been used for this study.

Research in cognitive psychology has revealed that uncertainty is central to solving complex problems (Schunn & Trafton, 2012). Indeed, uncertainty is important in the earliest stage of problem solving because how a problem is initially discovered and structured is a vital precursor to problem solving (Paletz & Peng, 2009). Design tasks are concerned with ill-structured or wicked problems, where the solutions are unknown throughout the design process (Cross, 2001). Exploring different ideas under conditions of uncertainty is a natural occurrence (Beheshti, 1993). As a consequence, uncertainty becomes a means to help a designer explore design alternatives. Within the early design stage, a designer also engages with the iterative design process of evaluation to gain valuable insights into the boundaries of the original problem (Dorst & Cross, 2001).

In reality, many possible solutions are generated when designing to meet specific requirements. This process involves redefining problems and developing solutions called co-evolution by Maher and Poon (1996) (Figure 2.5). This model fits Dorst and Cross's (2001) design creativity study in that they argue that creative design is not a matter of first defining a problem and then searching for a satisfactory solution. Creative design is a matter of the interchange of information between problems and solutions.

Gero and Kannengiesser (2014) also argued that there is no direct transformation from a problem to a solution. A designer needs to continually evaluate expected behaviours (Be) and behaviours derived from structures (Bs) until the structure performs its desired function. For instance, when a designer wants to design a structure to support a high-rise building they will consider of several possible solutions first (expected behaviour, Be), design them (structure, S), and then iteratively test (behaviour derived from structure, Bs) whether or not they achieve their goal (evaluation, Be⇆Bs). Uncertainty (problem space) and evaluation (co-evolution) form a unique relationship, which together with design alternatives (solution space) can be mapped onto the FBS model (Figure 2.7). Similarly, Tracey and Hutchinson (2016, p. 91) argue that 'Uncertainty is central to design and designers seek to reduce it via problem-solution co-evolution'.

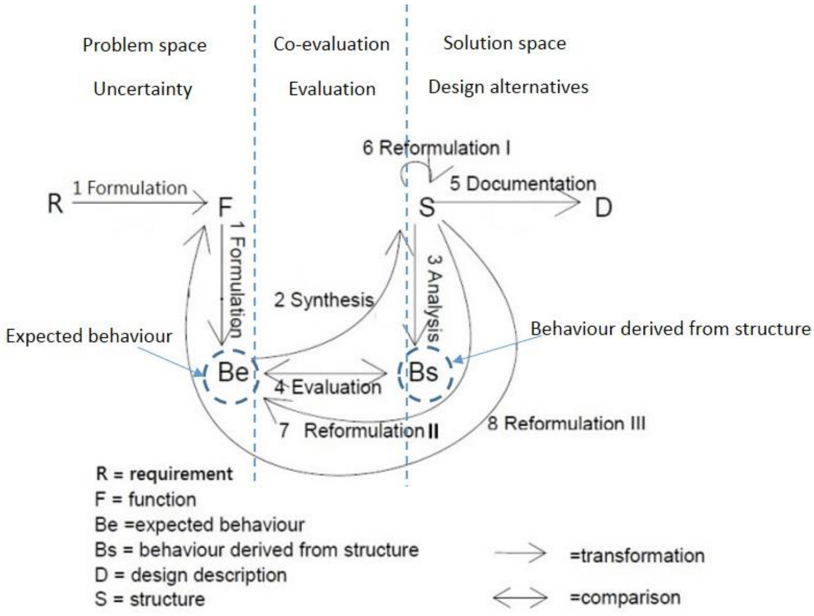


Figure 2.7. The mapping of uncertainty (problem space), evaluation (co-evolution) and design alternatives (solution space) into the FBS model (adopted from Gero & Kanengiesser, 2014).

2.3 Creative Design Processes

The FBS design model uses a process-oriented paradigm in order to understand design activities during designing. Conversely, the content-oriented approach aims to explore the impact of switching behaviours on designers' cognition as well as the creative design process. In the literature about design processes, the classification of design is generally categorised as routine and non-routine. Gero and Maher (1993) define the routine design as a process that follows a defined schema (e.g. predefined design space) where the expectations of what follows are defined by the schema. More specifically, routine design is the result of making design decisions in the context of a design situation in which all the decision variables are known a priori. Thus, in a routine design a designer operates within a defined, closed-state space of possible designs where the differences between designs can be characterised largely by the values selected for the design variables.

Non-routine design is a creative design process that often produces unexpected results (Cross & Dorst, 1999). It occurs when new variables are introduced into a design. According to Kolodner (1994), non-routine design is based on criteria and constraints that go beyond the stated constraints of a solution. It emerges from the complex interactions between different processes, such as: situation assessment, evaluation, assimilation, and redefinition of a problem. Cognitive research tends to regard design as an ill-defined problem, placing a redefinition of the problem at the centre of the design process (Visser, 1992). An ill-defined problem is characterised as having no definite criteria to test a proposed solution and a problem space that is not defined. In other words, the boundaries of what is considered relevant information are vague and there are no explicit rules of knowledge. To solve ill-defined problems the problem solver should deconstruct the entire problem into well-defined sub-problems and solve them individually. Creative design occurs when new design variables are introduced into the process of designing. Therefore, a creative designer functions ‘within a changing state space of possible designs; a state space which increases in size with the introduction of each new variable’ (Gero & Maher, 1991, p. 241) (Figure 2.8).

An ill-defined problem is often incomplete with regards to design requirements and has conflicting goals and solutions that are not always clearly defined. As a result, a redefinition of a problem or problem finding is necessary to gain insight into new solutions. The ways in which switching behaviour changes with designer cognition and resultant problem-finding actions needs to be analysed.

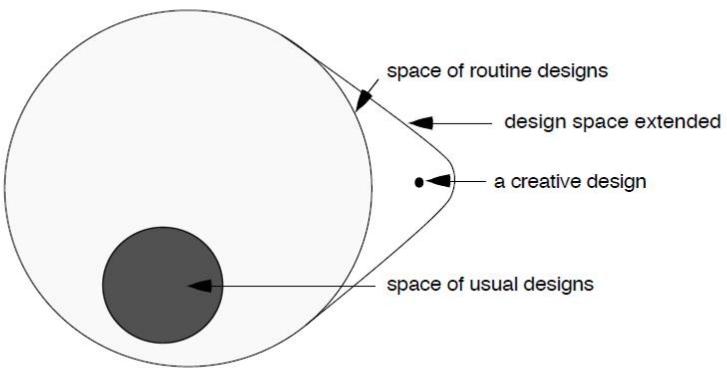


Figure 2.8. Shows the state spaces of routine design and creative design (Gero & Maher, 1991).

Different terms developed in protocol studies refer to problem finding, such as unexpected discoveries, situative inventions (S-invention) and co-evolution. The unexpected discoveries model of Suwa, Gero, and Purcell (2000) is a more comprehensive model for measuring design creativity. They describe unexpected discoveries as unanticipated findings that may occur as a result of perceptual activities that articulate tacit design semantics into visual-spatial forms through unanticipated findings by the later inspections (Akintoye et al., 2012). Goldschmidt and Porter (2004) believe that unexpected discoveries occur when designers' perceptions of external sources of inspiration stimulate imagination. This suggests that external representations can be more important than the representations themselves. Suwa et al. (2000) consider that unexpected discoveries are catalysts for the development of the design process and the evolution of the solution-space, arguing that there is an iterative interaction between the development of the solution-space and sparking new ideas about the problem-space.

S-invention is another key factor for improving the design process. According to Suwa et al. (2000), S-invention refers to designers' activities that extend beyond the initial definitions of the problem-space, helping designers to form new goals for the solution-space to address significant parts of the design problem. This enables designers to move beyond a synthesis of solutions that suits the given requirements (Akintoye et al., 2012). Moreover, Cross and Dorst (1999) posited the modelling of design creativity as a co-evolution for both problem and solution spaces. This co-evolutionary design is an approach to problem solving defined by Maher and Poon (1996). In this approach, the design requirements and design artefacts are formed disjointedly while mutually affecting each other. Kim and Maher (2008) asserted that in this approach the changes in the problem have an effect on the designer's insight on the solutions.

The aim of this study is to investigate the impact of switching behaviours on designers' cognition and a creative design process. The next section introduces different types of switching behaviours; how to analyse these switching behaviours will be introduced in Chapter 3.

2.4 Types of Switching Behaviours

A switching behaviour model is proposed (Figure 2.9) containing three types of switching behaviours that occur in mixed media design environments. The definition of these switching behaviours is shown in the following:

Eyes' switching refers solely to where designers *look*. For instance, during the CAD modelling process, a designer may map the current CAD model with its sketched layout to enhance their visual thinking. *Single switching* refers to where designers *look and execute* actions. They may switch from sketching to CAD modelling or from CAD modelling to sketching to progress their work. The strengths and weaknesses of these media are complementary as, for example, a designer may finish ground-floor CAD models and then sketch ideas for the first-floor layout. The main difference between eyes' switching and single switching is that single switching involves moving to another design media to continue design work, whilst eyes' switching involves using the same design media by retrieving visual information from the other media.

Integrated switching refers to where designers *look and execute actions involving multiple switches between the media*, focusing on a particular issue. For example, this may be where the designer of a stair designs to ensure that those using it can progress from one flight to the next in a convenient manner. This may be facilitated through the co-evolution process.

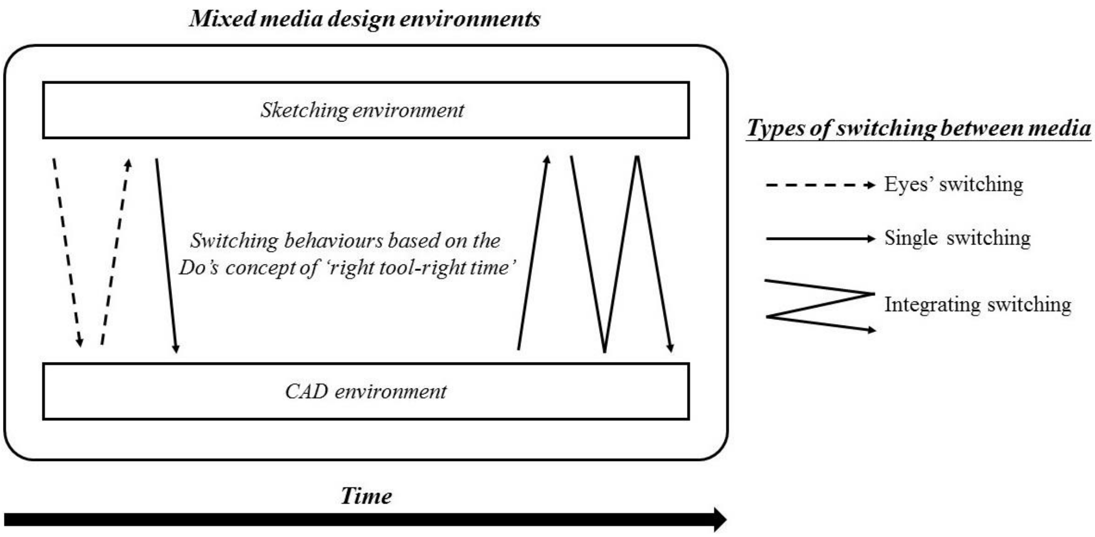


Figure 2.9. A switching behaviour model for mixed media design environments.

The first type of switching behaviour shown in Figure 2.9 (dotted line) is called *eyes' switching* and draws on Won's visual thinking protocol study of three types of seeing to analyse design activities (Won, 2001). They are 'seeing-imaging-drawing', 'seeing-as and seeing-that' and 'seeing-total design and seeing-detailed design'. Won's results show that designers spent more time on detailed design in CAD modelling because they could easily respond to the immediate visual feedback of the CAD models. On the other hand, designers spent more time on overall design when sketching.

The second type (solid line) is called *single switching* according to Rahimian, Ibrahim and Jaafar's (2008) summaries of the challenges and benefits of design media to fit designers' needs. The main benefit of sketching is to help designers record and compare different ideas on paper, whilst CAD modelling helps them focus on more detailed and realistic designs. The third type (zig-zag line) is called *integrating switching* because creative design is a matter of the interchange of information between problems and solutions (Dorst & Cross, 2001). Similarly, creative design concepts are often seen as iterative developments, where design problems and solutions evolve in a mutually adapted way (Wiltschnig, Christensen, & Ball, 2013). Given that the literature identifies three types of switching modes, the roles of sketching and CAD modelling become very similar in a mixed media design environment because they help a designer to achieve a goal at the appropriate time during the design process. The next chapter introduces the research methodology and research design used for this study.

Chapter 3: Research Methodology

The aim of this chapter is to outline the methods and research design utilised in the study. A protocol analysis methodology was selected by reviewing relevant literature to identify an appropriate research method to achieve the research aim. Two participants with at least two year's professional design experience and competence in both sketching and CAD modelling participated in the pilot study to test the coding scheme and experimental arrangements. A review of the pilot resulted in changes to the main study including revisions to the coding procedure as well as to the switching coding scheme. This chapter deals firstly with the reasons for selecting the protocol analysis methodology. Secondly, the use of protocol analysis as a research method is provided, describing its application in design study research. The third section explores the structure of the FBS coding scheme used in this study. This scheme facilitated an analysis of design activities using sketching or CAD modelling. Fourthly, details of the recruitment of participants and the research design are provided. Fifthly, the pilot study is described (preliminary outcomes of this study are presented in Paper Three (P 3) and in-depth analysis reports in Paper Four (P 4)). Finally, the last section describes how the pilot study was changed for the main study in Chapter 4.

3.1 Selection of Research Methodology

The protocol analysis methodology has been widely used to examine design activities in different design media environments (Bilda & Demirkan, 2003; Bilda & Gero, 2006; Kan & Gero, 2009; Kim & Maher, 2008). In order to select an appropriate research methodology, Table 3.1 shows 56 of 75 references cited in the literature review chapter that used protocol analysis and were published in top journals such as *Design Studies, Research in Engineering Design, Creativity Research Journal* and *Automation in Construction*. Although research topics are different, protocol analysis is a well-accepted research methodology to explore design activities. The verbalisations, actions and other signifiers of intermediary thoughts are recorded when the problem-solving process unfolds. The next section introduces protocol analysis.

Table 3.1. References cited from the literature review chapter using protocol analysis.

No.	References
1	Aliakseyeu, D. (2003). *A Computer Support Tool for the Early Stages of Architectural Design.* (PhD thesis). Eindhoven University of Technology, The Netherlands
2	Bilda, Z. & Demirkan, H. (2003). An insight on designers' sketching activities in traditional versus digital media. *Design Studies*, *24*(1), 27-50
3	Bilda, Z. & Gero, J. S. (2004). Analysis of a blindfolded architect's design session. In J. S. Gero, B. Tversky & T. Knight (eds.), *Visual and Spatial Reasoning in Design III*, Key Centre of Design Computing and Cognition, University of Sydney, 121-136
4	Bilda, Z. & Gero, J. S. (2006). To sketch or not to sketch? That is the question. *Design Studies, 27*(5), 587-613
5	Chen, Z. R. (2007). How to improve creativity: can designers improve their design creativity by using conventional and digital media simultaneously? *CAAD Futures 2007,* Australia
6	Cross, N. & Cross, A. (1995). Observations of Teamwork and Social Processes in Design, *Design Studies*, *16*(2), 143-170
7	Cross, N. & Dorst, K. (1999). Co-evolution of Problem and Solution Space in Creative Design. In J. S. Gero and M. L. Maher (eds.) *Computational Models of Creative Design IV*, Key Centre of Design Computing, University of Sydney, 243-262
8	Cross, N., Christiaans, H. & Dorst, K. (1996). *Analysing design activity*, Wiley & Sons, New York, NY
9	Dorst, K. (1996). The Design Problem and its Structure. In N. Cross, H. Christiaans & K. Dorst (eds.), *Analysing Design Activity*, John Wiley & Sons Ltd, Chichester, New York, 17-35
10	Dorst, K. & Dijkhuis, J. (1995). Comparing Paradigms for Describing Design Activity, *Design Studies*, *16*(2), 261-275
11	Do, E. & Gross, M. (1995). Sketching Analogies: Finding Visual References By Sketching, Computing in Design - Enabling, Capturing and Sharing Ideas, *ACADIA Conference Proceedings,* 35-52
12	Eckersley, M. (1988). The form of design process: a protocol analysis study, *Design Studies, 16*, 86-94
13	Ericsson, K. A. & Simon, H. A. (1993). *Protocol Analysis: Verbal Reports as Data* MA, MIT Press, Cambridge, Mass. Ehrlenspiel, K. (1995) *Integrierte Produktentwicklung*, Hanser, München
14	Do, E. (2005). Design Sketches and Sketch Design Tools. In K. Nakakoji, M. D. Gross, L.

Table 3.1. References cited from the literature review chapter using protocol analysis.

	Candy, & E. Edmonds (eds.). *KBS - Knowledge Based Systems* (18) 383-405, Elsevier Publisher
15	Gero. J. S. & McNeill, T. (1998). An Approach to the Analysis of Design Protocols, *Research in Engineering Design,* Springer Verlag, London
16	Gero, J. S. & Tang, H. H. (2001). Differences between retrospective and concurrent protocols in revealing the process-oriented aspects of the design process, *Design Studies 21*(3) 283-295
17	Goldschmidt, G. (1997) Capturing indeterminism: Representation in the design problem space, *Design Studies 18*(4), 441–445
18	Goldschmidt, G. (2003) Cognitive economy in design reasoning. In U. Lindemann (ed.) *Human Behaviour in Design*, Springer Verlag, Berlin, 53–62
19	Goldschmidt, G. (1992). Criteria for design evaluation: a process–oriented paradigm. In Y. E. Kalay (ed.). *Evaluating and Predicting Design Performance*, John Wiley & Son, Inc., New York, 67–79
20	Goldschmidt, G. (1994). On visual design thinking: the vis kids of architecture. *Design Studies, 15*(2), 158–174
21	Goldschmidt, G. (1990). Linkography: assessing design productivity. *Cyberbetics and System '90*, Singapore
22	Goldschmidt, G. (1991). The dialectics of sketching, *Creativity Research Journal 4*(2), 123–143
23	Goldschmidt, G. (1995). Visual displays for design: Imagery, analogy and databases of visual images. In A. Koutamanis, H. Timmermans, & A. Vermeulen, (eds.), *Visual Databases in Architecture,* Aldershot, Avebury, 53–74
24	Ibrahim, R. & Rahimian, F. P. (2011). Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction*, *19*(8), 978–987
25	Kan, J. W. T. & Gero, J. S. (2005). Can entropy indicate the richness of idea generation in team designing? *Proceedings of the 10th International Conference on Computer Aided Architectural Design Research in Asia (CAADRIA 2005),* New Delhi, India
26	Kan, J. W. T. & Gero, J. S. (2007). Can an objective measurement of design protocols reflect the quality of a design outcome? *International conference on engineering design (ICED 2007)*, Paris, France
27	Kan, J. W. T. & Gero, J. S. (2008). Acquiring information from linkography in protocol studies of designing. *Design Studies*, *29*(4), 315–337
28	Kan, J. W. T. & Gero, J. S. (2008). Do computer mediated tools affect team design creativity? *Proceedings of the 13th International Conference on Computer Aided Architectural Design Research in Asia(CAADRIA 2008)*, Chiang Mai, Thailand

Table 3.1. References cited from the literature review chapter using protocol analysis.

29	Kavakli, M. & Gero, J. S. (2001). Sketching as mental imagery processing. *Design Studies, 22*(4), 347–364
30	Kim, M. J. & Maher, M. L. (2005). Creative Design and Spatial Cognition in a Tangible User Interface Environment. *Computational and Cognitive Models of Creative Design VI,* J. Gero and M. L. Maher, University of Sydney, 233-250
31	Kim, M. J. & Maher, M. L. (2008). The impact of tangible user interfaces on spatial cognition during collaborative design. *Design Studies*, *29*(3), 222–253
32	Lin, C. (2003) Seeing Moving Seeing Model for Computer Media. *8th International Conference on Computer Aided Architectural Design Research in Asia*
33	Maher, M. L., Poon, J. & Boulanger, S. (1996). Formalising design exploration as co-evolution: A combined gene approach. *Advances in Formal Design Methods for CAD*, John S. Gero (ed.), Chapman & Hall.
34	Lloyd, P., Lawson, B. & Scott, P. (1995). Can concurrent verbalisation reveal design cognition? *Design Studies 16*, 237–259
35	Purcell, A. T. & Gero, J. S. (1998). Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology. *Design Studies, 19*(4), 389-430
36	Purcell, T., Gero, J., Edward, H. & McNeil, T. (1994). The Data in Design Protocols: the Issue of Data Coding. In N. Cross and H. Christiaans (eds.) *Data Analysis in the Development of Models of the Design Process*
37	Schon, D. A. (1983). *The Reflective Practitioner*, Harper Collins, New York
38	Schön, D. A. (1992). Designing as Reflective Conversation with the Materials of a Design Situation, *Knowledge-Based System*, (5.1), 3-14
39	Schon, D. A. & Wiggins, G. (1992). Kinds of seeing and their functions in designing, *Design Studies*, *13*(2), 135-156
40	Simon, H. A. (1983). Search and reasoning in problem solving, *Artificial Intelligence, 21*, 7-29
41	Suwa, M., Purcell, T. & Gero, J. (1998). Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies, 19*, 455-483
42	Suwa, M. & Tversky, B. (2001). How Do Designers Shift Their Focus of Attention in Their Own Sketches? In M. Anderson, B. Meyer, & P. Olivier (eds.) *Diagrammatic Reasoning and Representation*, Berlin, Springer, 241-260
43	Suwa, M. & Tversky, B. (1996). What Architects See in Their Design Sketches: Implications for Design Tools. *The Conference on Human Factors in Computing Systems (CHI'99),* 191-192
44	Suwa, M. & Tversky, B. (1997). What do architects and students perceive in their design sketches? A protocol analysis, *Design Studies*, *18*(4), 385-403

Table 3.1. References cited from the literature review chapter using protocol analysis.

45	Suwa, M., Purcell, T. & Gero, J. S. (1999). Unexpected Discoveries: How Designers Discover Hidden Features in Sketch. In J. S. Gero & B. Tversky (eds.) *Visual and Spatial Reasoning in Design*, Key Centre of Design Computing and Cognition, University of Sydney, 145–162
46	Suwa, M., Gero, J. & Purcell, T. (2000) Unexpected discoveries of design requirements: important vehicles for a design process, *Design Studies*, *21*(4), 539–567
47	Tang, H. H., Lee, Y. Y. & Gero, J. S. (2011). Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function-behaviour-structure coding scheme. *Design Studies, 32*(1), 1–29
48	Ullman, D. G., Wood, S. & Craig, D. (1990). The importance of drawing in the mechanical design process. *Computers & Graphics, 14*(2), 263–274
49	van der Lugt, R. (2005) How sketching can affect the idea generation process in design group meetings. *Design Studies, 26*(2), 101-122
50	Van Elsas, P. & Vergeest, J. (1998). New functionality for computer-aided conceptual design: the displacement feature, *Design Studies*, *19*(1), 81-102
51	Vermaas, P. E. & Dorst, C. H. (2007). On the Conceptual Framework of John Gero's FBS Model and the Prescriptive Aims of Design Methodology. *Design studies, 28*, 133-157
52	Visser, W. (1992). Designers' Activities Examined at Three Levels: Organisation, Strategies and Problem-Solving Processes, *Knowledge-Based System*, *5*(1), 92–104
53	Yamamoto, Y., Nakakoji, K. & Takada, S. (2000). Hands-on representations in a two-dimensional space for early stages of design, *Knowledge Based Systems*, *13*(6), 374–384
54	Williams, C. B., Lee, Y., Gero, J. S. & Paretti, M. (2013). Exploring the effect of the design prompt on students' design cognition, *ASME IDETC2013* DETC2013–13557.
55	Wiltschnig, S., Christensen, B. T. & Ball, L. J. (2013). Collaborative problem-solution co-evolution in creative design. *Design Studies*, *34*(5), 515–542.
56	Won, P. H. (2001). The comparison between visual thinking using computer and conventional media in the concept generation stages of design. *Automation in Construction, 10*(3), 319–325.

3.2 Protocol Analysis

The credibility of a study depends upon the research method chosen and the way in which research is conducted. Protocol analysis offers a potentially effective method for the controlled observation and experimental analysis of cognitive behaviour (Gero & Tang, 2001). Protocol analysis can be used to understand design processes, knowledge used, cognitive actions, and strategies employed. In the context of this study, an application of protocol analysis is to ask designers how they design an artefact. However, they usually find this question difficult to answer in detail. This is because designers often retain their design thoughts in their short-term memory while designing. Many studies (Ibrahim & Rahimian 2011; Kim & Maher, 2008; Suwa & Tversky, 2001) show that protocol analysis can comprehensively record designers' reasoning during the design process rather than simply relying on their design results for such insights.

There are two ways to collect protocol data: retrospective and concurrent (think-aloud) verbalisation (Dorst & Dijkhuis, 1995). Generally, retrospective verbalisation means that designers perform tasks and are asked afterwards about their thought processes during their design activities. Another approach is to video-record design sessions and to review recordings together with the designers, thereby enabling them to interpret what happened. However, it may be difficult for them to remember thought processes after an activity has been completed and the usefulness of this method is limited (Newell, 1990). Another problem is that designers may present their thought processes as more coherent and intelligent than they originally were; they may not report the thoughts they actually had during the design process and may instead report false memories. This may give a misleading impression of perfectly rational behaviour (Newell, 1990). Retrospection means that information must be retrieved from long-term memory and then verbalised. The disadvantage of this approach is that the retrieval process may not unearth all the information that was actually experienced during the design processes.

On the other hand, the think-aloud protocol requires designers to verbalise their thoughts while designing (Tang, Lee, & Gero, 2011; Van Someren, Barnard, & Sandberth, 1994). In other words, designers explain their thoughts whilst performing the task at hand. Unlike retrospective protocols for gathering verbal data, no set questions are asked. Designers are encouraged to give a concurrent account of their thoughts and to avoid interpreting what they are doing (Gero & Tang, 2001). This method is more successful because almost all of a designer's conscious effort is aimed at achieving the design task they are busy working on. This restricts the opportunities for them to reflect on their design activities and to refashion explanations of their activities. As such, the data gathered are very direct; there is no delay that results in altered data. The advantages of concurrent verbalisation fit the aim of this research because this process focuses on analysing designers' cognitive actions rather than using subjective self-reports (Salman et al., 2014). Therefore, concurrent verbalisation was selected as a suitable and robust approach for this study. Protocol studies involve the following steps (Ericsson & Simon, 1993; Kan & Gero, 2008): (1) proposing a research gap; (2) recruiting of participants and set-up of experiments; (3) recording the experiments; (4) transcribing protocol data; (5) selection and/or development of a coding scheme; (6) encoding the protocol data; (7) analysis of the protocol data; and (8) interpretation of results. To obtain meaningful research outcomes, an appropriate coding scheme is important and the approach used for this study is described below.

3.3 Function-Behaviour-Structure Coding Scheme for Mixed Media Studies

Many protocol design studies have adopted the FBS model to describe design processes and tasks (Gero & Kannengiesser, 2014). Some researchers argue that the definition of function has not been stable over the years and that the FBS model both describes actual designing and prescribes improved designing (Tang et al., 2011). The FBS coding scheme is defined as a process-oriented design theory in which designing is understood as a sequence of distinguishable stages. Six design issues and eight design processes of the FBS coding scheme (Figure 2.6) have been discussed in Chapter 2 section 2.2. The FBS design model was developed to distinguish between the design activities that occur in sketching and those that occur in CAD modelling (Figure 3.1). Based on the FBS coding scheme, the sketching environment consists of six design issues (Rs, Fs, Bes, Bss, Ss, and Ds) while the CAD modelling environment also involves six design issues (Rc, Fc, Bec, Bsc, Sc and Dc). These enable different distributions of design issues to be collected and analysed. This technique has been applied in the main study and reported in Papers Five, Six and Seven.

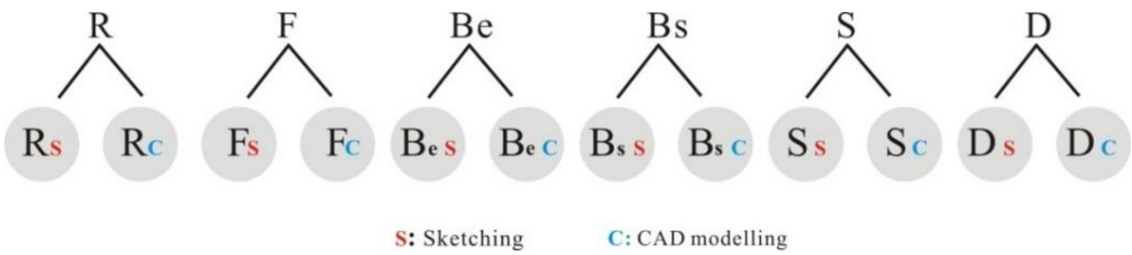


Figure 3.1. Development of the FBS design model for coding sketching and CAD modelling activities.

3.4 Participant Recruitments and Research Design

This study has explored how designers interact with sketching and CAD modelling when designing. Designing is a high level cognitive activity. Most of the empirical research into designers' behaviours includes a relatively small number of participants and seeks to understand specific cognitive processes (Akin & Moustapha, 2003; Ball, Ormerod, & Morley, 2004). The participant recruitment approach was approved **(H-2011-0368)** in Appendix 2 by the Human Research Ethics Committee at the University of Newcastle. Eight designers were recruited in this study. Protocol analysis with eight designers is a relatively large scale cognitive study because each designer participates in two sessions using SMM and AMM. Therefore, the quantity of eight designers is capable of producing comprehensive data analysis suitable for the level of a PhD study.

Participants were initially identified from those who could best satisfy the selection criteria. To be included the participants needed: (1) a person who has the requisite 3 + 2 years educational qualifications plus 2-year practice experience and who has passed the registration examination to practice as an architect; (2) competence in both sketching and CAD modelling; and (3) competence in practising and communicating design in English. During the protocol data collection, two to eight architectural designers were recruited and reported in different papers in the following (Table 3.2).

Table 3.2. Participants recruitment in the study and reported in different papers.

Number of participants	Stages of the study	Reported in the papers
N/A	Framework of mixed study	Paper One (Conference paper)
	Switching coding scheme	Paper Two (Conference paper)
Two designers	Pilot study	Paper Three (Conference paper) Paper Four (Journal paper improved from Paper Three)
Four designers	SMM study	Paper Five (Journal paper)
Six designers	AMM study	Paper Six (Journal paper)
Eight designers	SMM versus AMM study	Paper Seven (Journal paper)

Paper one provides the framework and identifies a gap for a mixed media design study that developed as part of the overall study. Paper Two expands upon the literature reviewed in Paper One, covering different types of design media research and focuses on switching behaviour in mixed media design environments. Paper Three builds upon the research design section described in Paper Two and reports the conduct of a pilot study. Paper Four expands on Paper Three to solidify the preliminary outcomes. Paper Five further explores Paper Four involving four designers to focus on the roles of design media using the SMM approach as part of the main study. Paper Five expands upon Paper Four involving six participants using the AMM approach to solidify the analysis of design activities as well as of switching behaviours as part of the main study. Paper Seven expands upon Paper Five and Paper Six to solidify the main study outcomes involving eight participants using both SMM and AMM approaches. The outcomes are discussed in relation to two aspects: the roles of design media and designers' reflections.

Another consideration for experimental settings is the development of a design task suited to the research aims. Normally a 60 to 90 minute protocol task produces sufficient data and a manageable protocol size (Dorst, 1996). Dorst proposed that design tasks be challenging, realistic, appropriate, not too large, feasible in the time available, and within the scope of knowledge of the researchers. Architectural designers often design buildings and this study provided a basic floor plan with its CAD model (Figure 3.2). Participants were asked to use this model to design a building for different purposes: an architectural office, a dream house and an art gallery (included in Appendix 4). The three design briefs were randomly assigned to designers. These tasks were appropriate because each task could be completed in approximately 75 minutes. ArchiCAD software was selected for this study as it is a popular CAD system used in design schools and industry, and it enables a designer to create a virtual building with 3D structural elements like walls, doors and other materials. Furthermore, all participants were already familiar with this software and did not require further training. The challenge was to use the 2D layout and the 3D model and produce a design for different purposes.

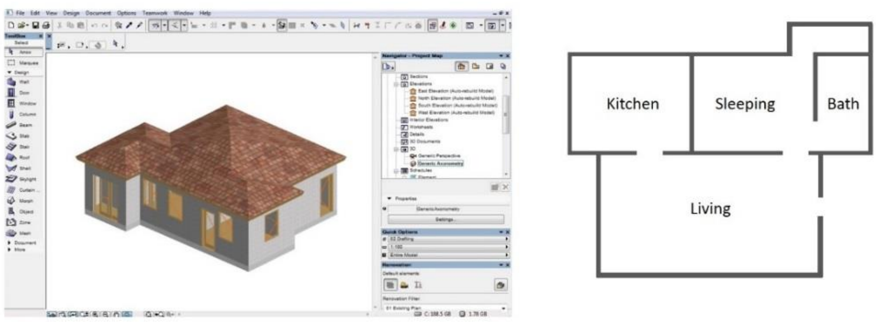
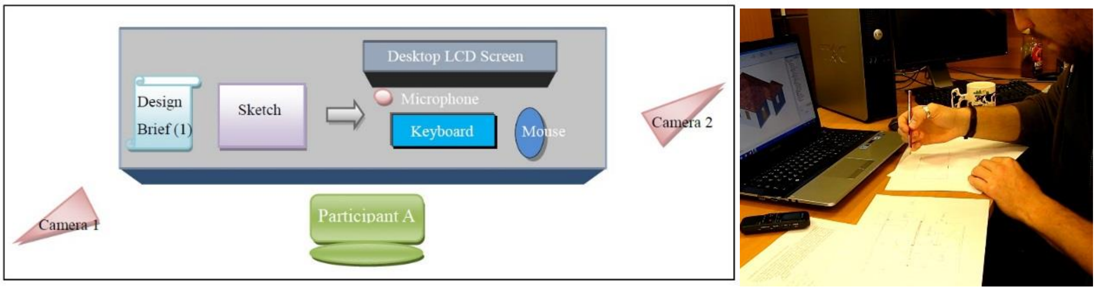


Figure 3.2. The experimental CAD model with its 2D layout.

Figure 3.3 shows the equipment used in the SMM and AMM design sessions. A digital video recording (DVR) system was set to record two different views on one computer screen. A camera was used to monitor a designer's behaviour, while the other view provided a video stream directly from the designer's screen. This enabled the researcher to simultaneously observe designers' switching between the design media. A typical computer configuration with a vertical screen, keyboard, mouse, as well as pencil and paper were used. Participants could use their own laptops if they preferred.

In SMM, designers were asked to sketch and then use CAD, whilst in AMM participants had the freedom to use both sketching and CAD modelling at will.

<u>The SMM experiment set-up:</u>



<u>The AMM experiment set-up:</u>

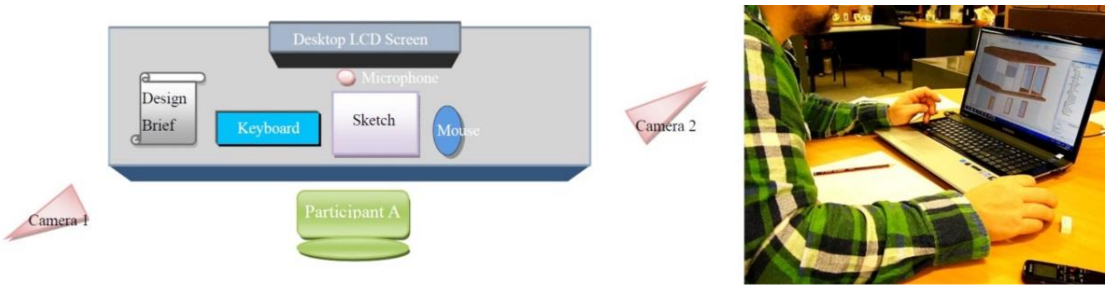


Figure 3.3. The SMM and AMM experiment set-ups.

3.5 The Pilot Study

This section presents the results of a preliminary protocol study of design activities of architectural designers. The aim is to examine the similarities and differences in cognitive behaviour using the SMM and AMM approaches. Two participants with at least two year's professional design experience and a Bachelor of Design degree, and competence in both sketching and CAD modelling participated in the study. Video recordings of these participants working on different projects were coded using the FBS coding scheme. The design protocols used for the pilot study included recording all forms of designers' overt behaviours, such as verbalisation, sketching, CAD modelling, and switching between media. Based on observations made during the study, when the think-aloud method was used, participants were not able to verbalise when they switched media. Table 3.3 shows examples of the FBS codes of the AMM protocol before switching interviews.

Table 3.3. Example codes of the AMM protocol before interviews.

Numbers	**Context**	**Code**	**Notes**
25	think about circulation of the door	Fs	N/A
26	draw an arrow	Ds	N/A
27	check the CAD model with views of different angles	Bsc	N/A

Table 3.4 shows examples of design switches including 'eye' and 'eye with hand' from sketching to CAD modelling, and from CAD modelling to sketching. Participants were interviewed after the AMM session and asked to identify and explain their switches.

Table 3.4. Examples of the participants' switches.

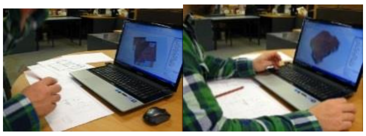
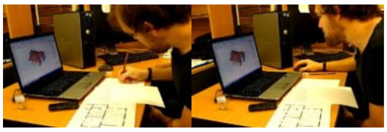
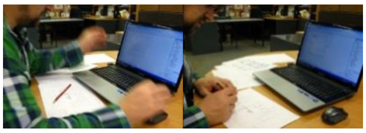
Design switches	Types	Participant A	Participant B
Sketching→ CAD modelling (S→C)	Eye		
	Eye and hand		
CAD modelling →Sketching (C→S)	Eye		
	Eye and hand		

Table 3.5 inserts interviews as new segmentations. This enabled the FBS codes to be refined after the switches due to the vagueness of natural language. For example, the code of the segment 'check the CAD model with views of different angles' was revised from Bsc to Dc since the switch interviews impacted on the codings.

Table 3.5. Example codes of the AMM protocol with switch interviews.

Numbers	Context	Code	Notes
25	think about circulation of the door	Fs	N/A
26	draw an arrow	Ds	N/A
27 Insert the switch-1	Once the sketching design process was completed through sketching I moved it to the CAD model to realise the design completed through the sketching process. Using the sketched design as a reference point to help the design to be completed in the CAD environment.	Dc	(S→C) insert switch interviews
28	check the CAD model with views of different angles	Dc	Bsc→ Dc

Since the design sessions and participants varied, the study normalised the frequency distribution of design issues by converting these to occurrence percentages, as shown in Figure 3.4. Participant A and participant B produced similar distributions for design issues in SMM and AMM. The six design issues can be divided into three groups, as follows: structure

(S) and documentation (D) > behaviour derived from structure (Bs); expected behaviour (Be); and function (F) > requirement (R). It means that the participants spent the most efforts on making product structure (S) and documentation (D) on the paper/CAD models and spent less efforts on reviewing design requirements (R). In the AMM design sessions, documentation (D) of participant A was significantly higher than that of participant B (34.1% > 12.5%). In contrast, requirement (R) of participant B was significantly higher than that of participant A (11.8% > 3.2%). The preliminary outcome was reported in Paper Four.

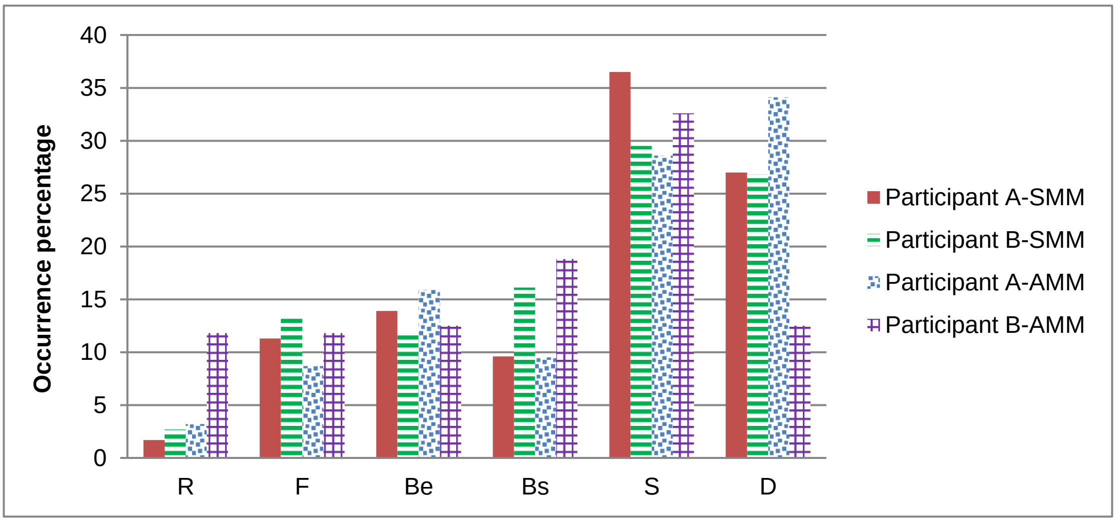


Figure 3.4. Occurrence of design issue of participants A and B in SMM and AMM sessions.

As shown in Table 3.5, the switching interview (no. 27) is content-oriented and contains more than one code. For example, 'moved it to the CAD model' is documentation (D) and 'using the sketched design as a reference point' is another documentation (D). The FBS coding scheme is process-oriented; one code for one design issue. Therefore, a content-oriented coding scheme needed to be developed for coding switching behaviours in next section.

3.6 Refinements for the Main Study

Due to the number of participants in the main study, two issues from the pilot study needed to be improved. The main study required a clear coding procedure. The coding procedure in mixed media design environments is more challenging than in a single design environment as designers switch between media. After transcribing an interview, video recordings were reviewed so that utterances could be matched to the design environment used. Transcriptions of the utterances that occurred in the CAD environment (using a mouse and keyboard) are shown in green, whilst those that occurred in sketching (with pencil and paper) are red (Figure 3.5). After segmentation, codes ('c' [for CAD] and 's' [for sketching]) were used to indicate which utterances occurred in which design environments.

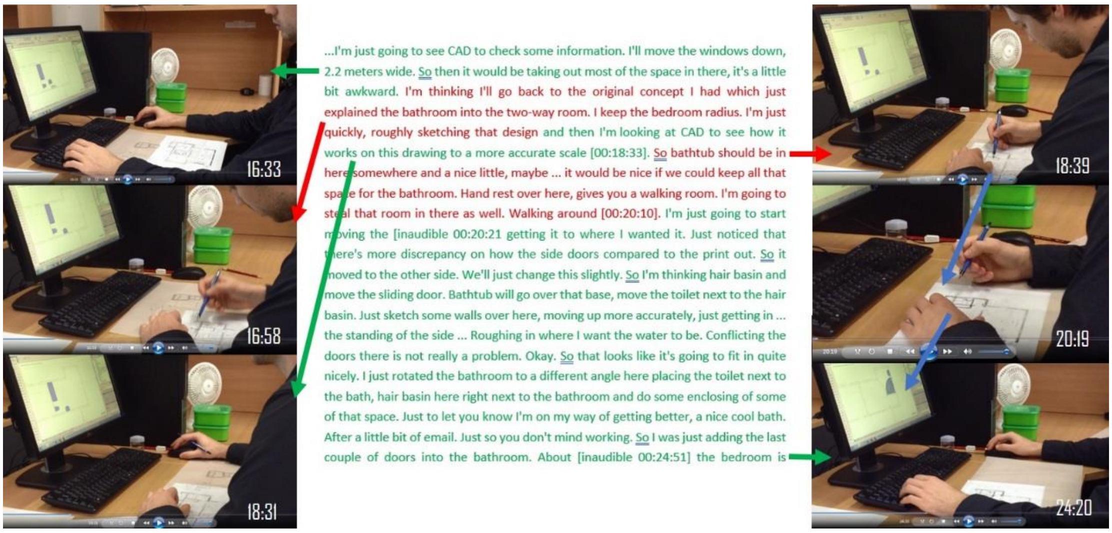


Figure 3.5. Coding procedure for mixed media design environments.

Appropriate design protocols for this study included recording all forms of the designers' overt behaviours such as their utterances, sketching, CAD modelling and switching between media. Think-aloud method was limited as each switching behaviour was brief (taking only a few milliseconds), participants were not able to verbalise their reasons for switching. Therefore, on completion of the mixed media sessions, participants were asked to review videos of their design actions and explain the reasons for their switches. These were then added to their transcriptions and are shown in blue in Table 3.6.

Table 3.6. A method to retrieve switching data.

Utterances	Recording methods
I'm just going to see CAD to check some information. I'll move the windows down, 2.2 meters wide. So then it would be taking out most of the space in there, it's a little bit awkward.	Think aloud
(CAD→SK) – 'space planning in sketch'.	Interview with video
I'm thinking I'll go back to the original concept I had which just explained the bathroom into the two-way room. I keep the bedroom radius. I'm just quickly, roughly sketching that design.	Think aloud
(SK→CAD) – 'get more accurate scale'.	Interview with video
…and then I'm looking at CAD to see how it works on this drawing to a more accurate scale [00:18:33].	Think aloud
(CAD→SK) – 'space planning, faster to sketch'.	Interview with video
So bathtub should be in here somewhere and a nice little, maybe ... it would be nice if we could keep all that space for the bathroom. Hand rest over here, gives you a walking room. I'm going to steal that room in there as well. Walking around [00:20:10].	Think aloud
(SK→CAD) – 'conceptual plans are developed in my mind, now I am documenting in CAD to ensure they work when drawn at scale'.	Interview with video
I'm just going to start moving the [inaudible 00:20:21 getting it to where I wanted it. Just noticed that there's more discrepancy on how the side doors compared to the print out. So it moved to the other side. We'll just change this slightly. So I'm thinking hair basin and move the sliding door. Bathtub will go over that base, move the toilet next to the hair basin. Just sketch some walls over here, moving up more accurately, just getting in ... the standing of the side ...	Think aloud

In addition, Table 3.7 provides examples of participants' switching behaviours. It contains several types of switching behaviours: CAD→SK→CAD, SK→CAD→SK, CAD→SK, and SK→CAD. The reasons for their switching behaviours were also provided.

Table 3.7. Examples of interview participants' switching behaviours.

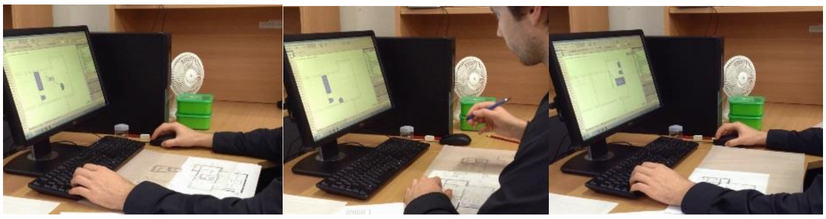
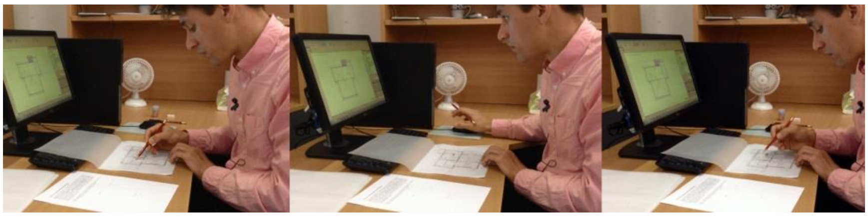
Examples of switching behaviours	Interview participants' switching behaviours
Participant A: CAD→SK→CAD	 'Try conceptual design when drawn at scale in CAD is not working properly, then try alternatives sketches until finding a design that does work in CAD'.
Participant B: CAD→SK→CAD	 'I came across a design issue in CAD, something I thought was going to fit did not, and thus is was back to the drawing board to test new design ideas, and test the sketch in the CAD environment'.
Participant C: SK→CAD→SK	 'Quick glances at computer just to clarify thinking, ideas are still being kept on the paper, being drawn'.
Participant D: CAD→SK	 'Got stuck on CAD modelling so using sketch to think of different space arrangement'.
Participant E: CAD→SK→CAD	 'I was switching back and forth between sketching and modelling environments so I can finalise my design intentions as I satisfy the briefs requirements'.

Table 3.7. Examples of interview participants' switching behaviours.

Participant F: SK→CAD	 'Transferring the sketch plan to the CAD environment'.
Participant G: SK→CAD→SK	 'Referring to the sketch and continuing modelling in CAD'.
Participant H: CAD→SK→CAD	 'Still trying to resolve the staircase I wanted to maximise the walls because it was meant to be an art gallery and I decide to stick it in the centre of the room so it would give the absolute maximum space and go up to the top of gallery but I was trying to line it up on the two sketches with the staircase and keep the front glass for the commercial premises; hating all the stairs and everything that was there in the very limited libraries. None of them I would use normally but using them because I don't have time'.

Many related studies (including Gero & Tang, 2001; Bilda & Gero, 2007; Kim & Maher, 2008) have adopted Suwa, Purcell and Gero's (1998) Physical-Perceptual-Functional-Conceptual (content-oriented) coding scheme to analyse interviews to study design cognition so this study will adopt it to develop a switching coding scheme. One of the most informative investigations explored spatial cognition by comparing tangible user interfaces (TUIs) and graphical user interfaces (GUIs) and found that TUIs can enhance designers' spatial cognition (Kim & Maher, 2008). The main study adopted several categories from the TUIs' coding scheme (action, perception, goal, and collaborative levels) to analyse switching behavioural actions. The action-level and collaborative-level coding categories will not be included in switching coding scheme since switching itself is an action and this study is based on the individual designer study. Finally, a media-level was added to the switching coding scheme to characterise switching behaviours at three levels: perception, media and concept levels (Table 3.8).

Table 3.8. Switching coding scheme based on TUIs study (Kim & Maher, 2008).

Levels		Descriptions
Perception level		*Perceptual activities*
	P-visual	Attend to visual features such as scale, shape, material etc.
	P-relation	Attend to objects/spaces relationship including orientation
Media level		*Environmental features*
	E-cad	An environment supports designers more detailed and realistic design features
	E-sketching	An environment supports designers to explore alternatives and to compare them
Concept level		*Focus on one intention one goal*
	G-iterations	Multiple switches by focusing one intention to achieve a goal

The TUIs study used a retrospective approach. Video recordings were used as prompts to collect verbal data from participants. These were examined using content-oriented coding schemes to understand designers' spatial cognition. This study collected and analysed interview data relating to switching behaviours. Table 3.9 summarises the methods of protocol data collection and coding schemes used for the AMM study.

Table 3.9. The methods of data collection and coding schemes used for the AMM study.

Types of data collection	Approaches	Coding schemes
Whole design sessions without switching interviews	Think aloud	Adopted Gero's FBS coding scheme (process-oriented)
Switching behaviours only	Interview with video aids	Three-level coding scheme (content-oriented)

Four, six and eight participants were recruited in the SMM, AMM and SMM versus AMM studies respectively. To improve the reliability of the protocol segmentation and coding results, the Delphi method was adopted (Gero & McNeill, 1998). Linstone and Turoff (1975, p. 3) state that 'Delphi may be characterised as a method for structuring a group communication process so that the process is effective allowing a group of individuals, as a whole, to deal with a complex problem'.

The crucial features of the Delphi method involve participants in four steps (Linstone & Turoff, 1975): (1) exploring the issues and contributing additional information relevant to the issues; (2) coming to an understanding of how the group views the issues; (3) exploring significant disagreements (if any), to reveal the underlying reasons and to evaluate them; and (4) evaluating all previously collected information. In Bilda et al.'s protocol studies (Bilda & Gero, 2007; Bilda, Gero, & Purcell, 2006), the Delphi method was adopted to verify the coding segments used for analysis. The transcripts were coded twice, with a one-month period between the two coding phases. The purpose of the interval was to avoid the researcher remembering how they previously coded segments. Resolving any differences in the two rounds was a judgement call made by the researcher. Gero, Jiang and Williams (2012) claimed that utilising the Delphi method enabled coder reliability of 85–95% to be reached. The percentage agreement between the individual rounds and the final arbitration was approximately 86%, which confirms the reliability of the coding results of this study.

This study also adopted Bilda et al.'s approach. All participants completed a design based on the briefs allocated to them (Table 3.10), and their design activities were videoed. The average numbers of FBS design issues of the eight participants were 78 in SMM and 80 in AMM during sketching. 167 codes occurred in SMM and 195 codes occurred in AMM during CAD modelling. The two sets of data collected from participants were protocol data and interviews. The protocol data were generated by the think-aloud method and analysed using the FBS coding scheme. Secondly, after task completion, participants were shown videos of their switching behaviours and interviewed about what had occurred. The next chapter presents the main study results involving three sections: the SMM study, the AMM study, and the comparison study between SMM and AMM.

Table 3.10. Design outcomes from participants.

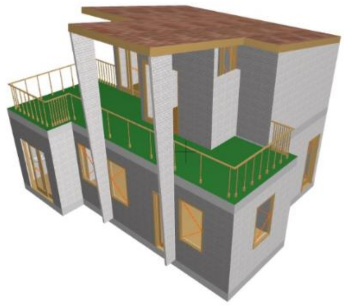
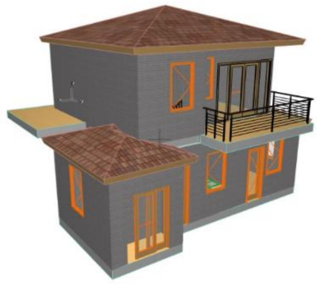
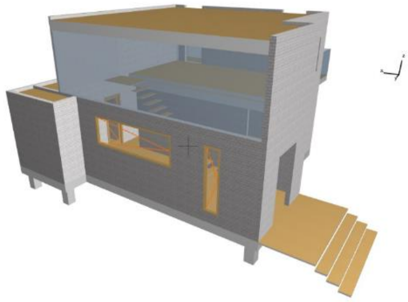
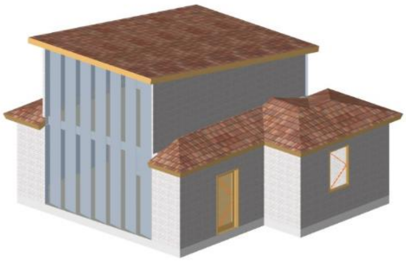
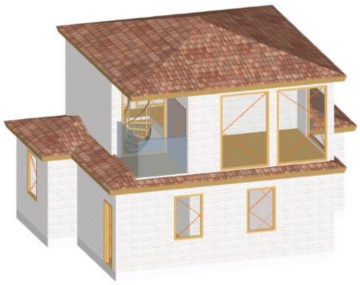
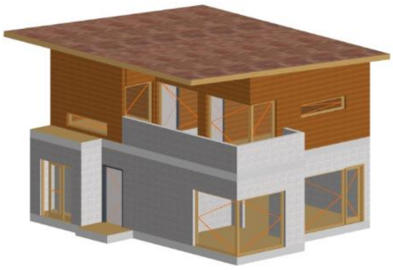
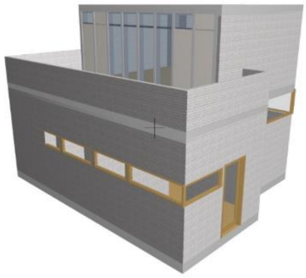
Participants	SMM sessions	AMM sessions
A	 Architecture office design	 Dream house design
B	 Architecture office design	 Dream house design
C	 Art gallery design	 Architecture office design
D	 Dream house design	 Art gallery design

Table 3.10. Design outcomes from participants.

E	 Architecture office design	 Dream house design
F	 Art gallery design	 Architecture office design
G	 Dream house design	 Art gallery design
H	 Dream house design	 Art gallery design

Chapter 4: Data and Discussion

This chapter introduces the main study results and tests of the hypotheses developed in the literature review chapter. Results of the main study are presented in three sections; results of the SMM study in section 4.1, results of the AMM study in section 4.2, and comparison between the SMM and AMM studies in section 4.3. The findings of the SMM study are presented in Paper Five. The findings of the AMM study are presented in Paper Six. Paper Seven compares the results between the SMM and AMM approaches.

4.1 The SMM Study

In the SMM study, four designers were invited to complete different architectural design tasks (section 3.4). They were asked to sketch first and then model their designs using CAD. The FBS coding scheme was adopted to analyse their cognitive actions. Even though a stereotypical outcome of CAD modelling is primarily documentation (Verstijnen et al., 1998; van Elsas & Vergeest, 1998), researchers have argued that CAD modelling could support conceptual design (Chen, 2007; Aish, 1986). Questions remain about what factors change CAD modelling roles to supporting conceptual design in the SMM design environment.

4.1.1 Distributions of design issues and design processes in the SMM and CAD modelling

Results from the study indicate that the four participants shared a similar distribution of design issues (Figure 4.1). The majority of cognitive effort was expended reasoning about the structure and the behaviour derived from the structure (Bs) (>20%). The design issue of requirement (R) had the lowest cognitive focus (<6%). Noticeable differences were observed among the participants on the issues of requirement (R) (5% difference between participants A and D), function (F) (8.6% difference between participants A and D), expected behaviour (Be) (6.2% difference between participants B and C), behaviour derived from structure (Bs) (16.3% difference between participants C and D), structure (S) (18.8% difference between participants B and C), and description (D) (6.7% difference between participants C and D). Participant C's design behaviour differed to others in terms of the (Be), (Bs), (S) and (D).

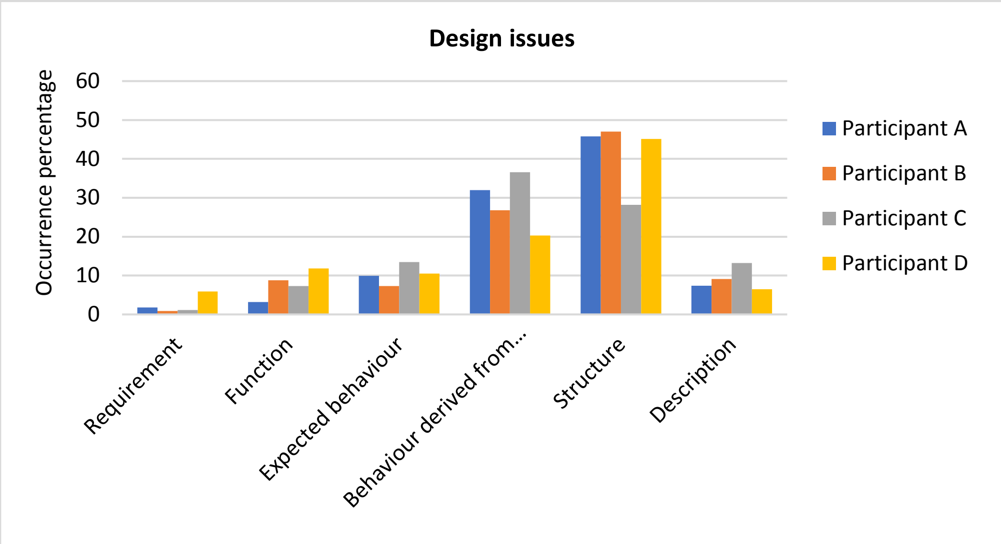


Figure 4.1. Design issue distributions in the SMM design environment.

A syntactic design process is one that presumes all segments are cognitively related to their immediate preceding segment. They are design processes that transform from one segment to the other (Williams et al., 2013). In this study, participants shared a similar design process distribution (Figure 4.2). The majority of time spent was in the design process reformulation I. However, participant C spent the most time on evaluation. The following sections analyses participants' FBS distributions in terms of design issues and design processes in CAD modelling to understand the roles of CAD modelling in the SMM design environment.

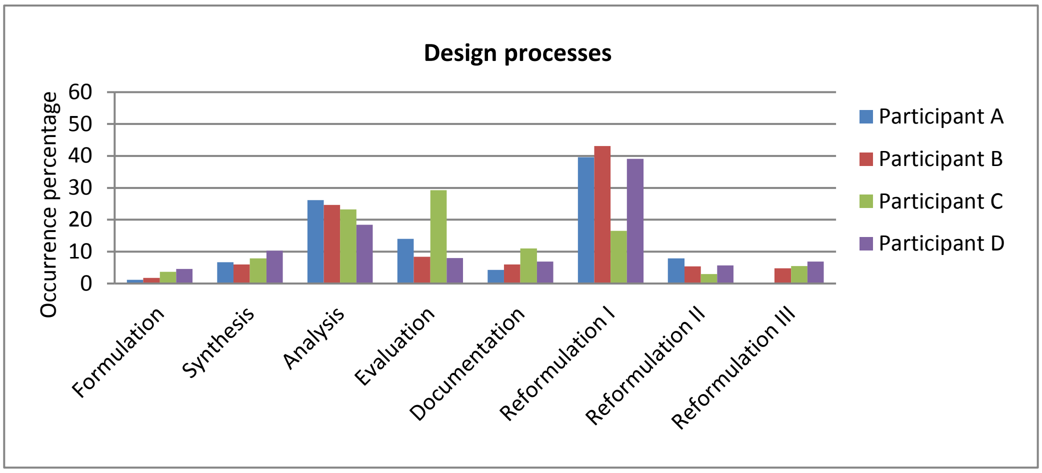


Figure 4.2. Design process distributions in the SMM design environment.

In the CAD modelling design environment it was observed that participants expended the majority of their cognitive effort considering design issues related to structure (approximately 30~52%) and behaviour derived from structure (23~38%) (Figure 4.3), as well as design processes of reformulation I (19~47%) and analysis (21~33%) (Figure 4.4). This suggests that most participants focused mainly on modelling the solution structures of their final designs. However, only participant C spent the majority of his cognitive effort on the design process of evaluation (30%) that concerned expected behaviour (Be) and behaviour derived from structure (Bs). This indicates that participant C's reasoning processes were different to other participants in CAD modelling (Figure 4.4).

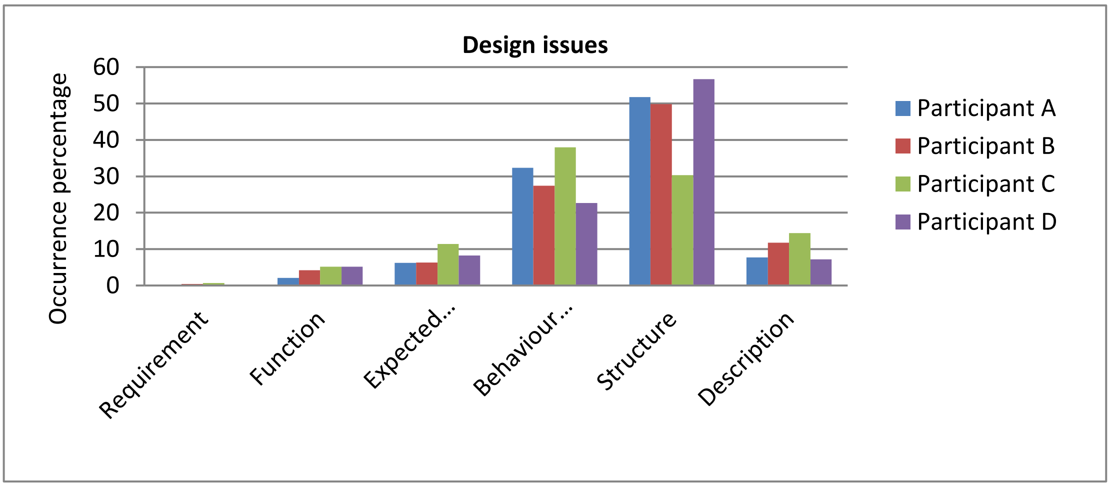


Figure 4.3. Design issue distributions in CAD modelling.

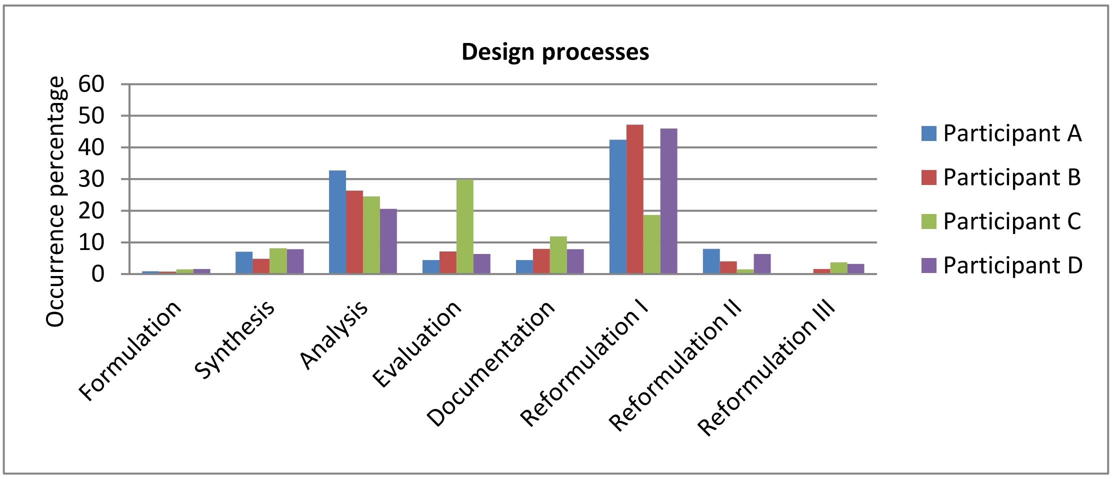


Figure 4.4. Design process distributions in CAD modelling.

4.1.2 Dynamic models to visualise the design process in CAD modelling

Figures 4.5 and 4.6 show the dynamic models of participants B and C during the CAD design process. Dynamic models using the linkoder software (Gero et al., 2011) make it possible to visually describe design moves using different colours. Figure 4.5 shows that participant B focused on reformulation I (light blue, S→S) and analysis (yellow, S→Bs) in the CAD modelling. The two peaks are caused by reformulation I and analysis around segments 26 and 100. This shows that participant B mainly focused on structure-related issues such as object dimensions and material selections in CAD modelling.

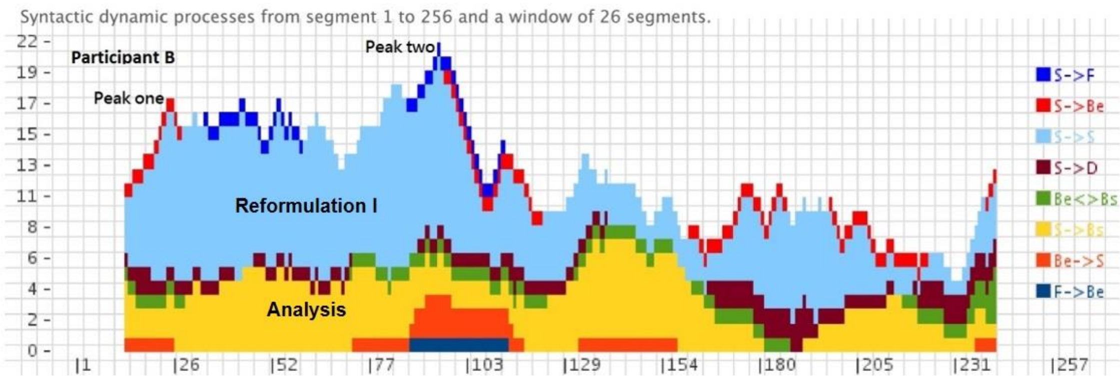


Figure 4.5. Participant B, dynamic model of the CAD modelling process.

Figure 4.6 shows that participant C spent the majority of his reasoning on the design processes of evaluation (green, Be→Bs) and analysis (yellow, S→Bs). The two peaks result from evaluation, analysis and reformulation I around segment 84 and 230. This reveals that participant C mainly focused on the design process of evaluation between problem and solution spaces.

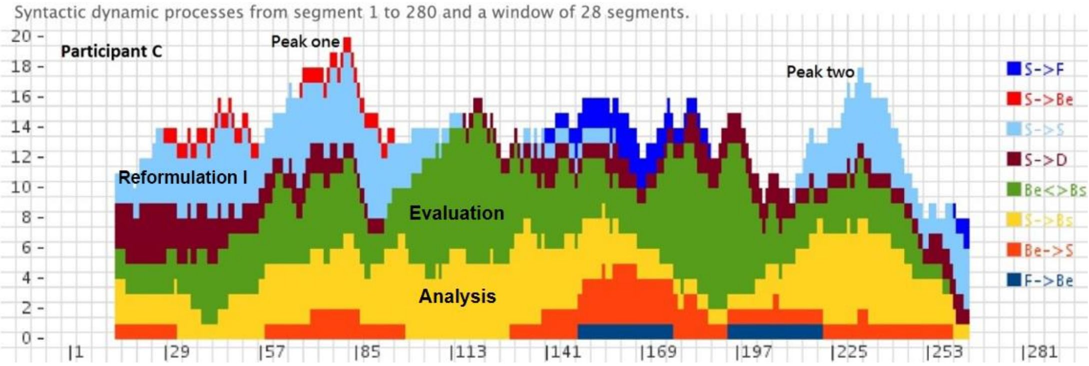


Figure 4.6. Participant C, dynamic model of the CAD modelling process.

4.1.3 Uncovering uncertainty through dissatisfaction with sketches

To explore the factors that changed the roles of CAD modelling in the SMM design environment, it was informative to look at the participants' design protocols of segmentations at the end of the sketching sessions. A review of every segment indicated that participants A, B, and D were satisfied with their sketches. Only participant C was dissatisfied with his sketches, so his CAD modelling design phase remained uncertain (Figure 4.7). Although the majority of his effort was devoted to evaluating his design alternatives, participant C was nevertheless dissatisfied with his sketching, stating:

> *'Okay, so I'm done with the drawings, I think. I don't like it. I like going back to the drawing, so - but I understand the exercise, so now I'm going to try, from what I have drawn - from what I have drawn which is very rough, to make it work on the model, which should be easy enough.'*

However, participant C was dissatisfied with his sketches and tried to build a CAD model based on his rough sketches, and thought this would be easy. This illustrates participant C's uncertainty which turned the CAD design phase into a creative design process. The protocol analysis in terms of the FBS distributions and dynamic models empirically support Tracey and Hutchinson's argument: When uncertainty arises during a design task, producing new solutions to a problem involves a process in which missing information is recovered from the design alternatives. This phase involves the iterative process of evaluation to reduce uncertainty (Tracey & Hutchinson, 2016). Although the findings were generalised by the small sample size, the empirical evidence makes sense answering the reason of role changes in CAD design processes.

Figure 4.7. Participant C was dissatisfied with his sketches.

4.1.3 Participants' comments

Participants provided comments on completion of their experiments. These (below) pointed to a single solution, which is integrating sketching into the CAD modelling design process.

> *'By restricting the process to the sketching as design and then CAD as documentation only and no allowance to switch between them the capacity of each form is limited. Some design will always happen in the CAD environment, and some documentation (even if only for the designers' own records) will happen best with pencil and paper, so assuming that the division is clear and discreet is wrong. It is generally not possible to memorize a design and then CAD it up correctly, so referring to the sketch is vital'.*

'Without being able to switch it took too long to try different design combinations if the first design didn't fit within the building properly. Then I was left to try to design straight into CAD which is much less intuitive then sketching'.

'I personally found the design process more difficult as once I had sketched my ideas and then placed them in CAD I could not sketch further ideas. The problem of this approach is the practitioner need to 'fix' encountered problems on the screen and not draw by hand possible alternative solutions. This process is much slower then returning to the 'thinking hand' for developing new ideas'.

After reviewing participants' design segments, participant A mentioned that he wanted to use sketching during the CAD modelling process when sketches and CAD models did not match each other (Table 4.1). Whatever the mechanism, the assumption is that uncertainty with current designs stimulates new solutions to solve problems using different design environments.

Table 4.1. Participant A's design protocol during CAD modelling.

No.	Utterance	Code
177	'I hope that would be a solution enough. Well … okay. Let's think about reconfiguring our reception area. If we had a bathroom on the outside of this building … that won't work.'	Bsc
178	'Okay this is the point in time when I want to take out a pencil and start sketching again.'	Dc
179	'The reception desk … a little there some chairs that are not working here.'	Bsc

Lastly, from empirical evidence, dissatisfaction with prior sketches resulted in CAD modelling being used to support conceptual design. Being dissatisfied with sketches, the whole CAD design phase became uncertain. This played a key role driving designers to new solutions and involving considerable cognitive effort on evaluation. This also fits Christensen and Schunn's (2009) study because higher uncertainty occurred at the beginning of the design process (e.g. here is sketching). Once designers satisfied their sketch outcomes, the following CAD design phase was mainly for documentation because uncertainty lowered. This phenomenon is illustrated below (Figure 4.8):

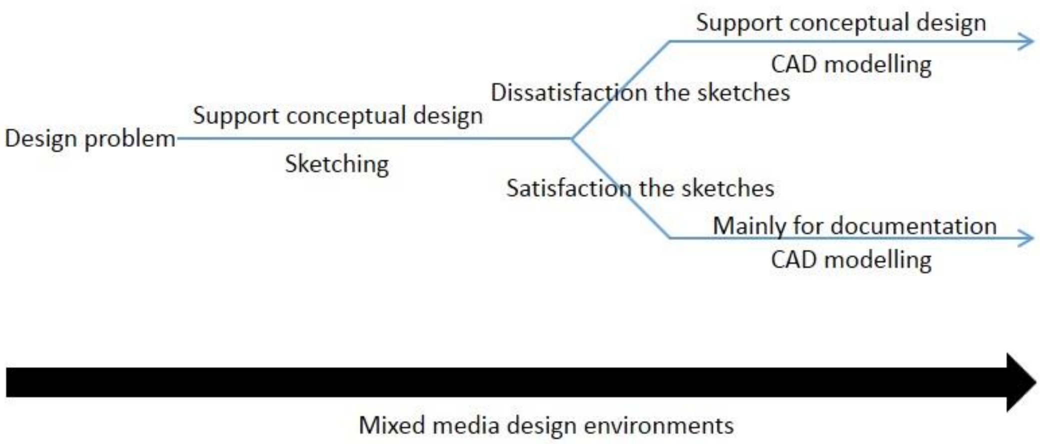


Figure 4.8. A diagram showing how CAD modelling is used differently in mixed media design environments.

4.1.4 Summary

Results show that designers spent the majority of their reasoning effort during the CAD modelling session, which had a significant influence on the overall FBS design issues and process distributions. The study explored how four designers in the SMM design environment focused on the use of CAD in the design phase. Participants A, B and D spent the majority of their cognitive effort on the design process of reformulation I (S→S). This suggests that they were using CAD modelling for documentation because many segments were coded according to the design issue of structure (S) for building components or selecting materials. However, participant C spent the majority of his cognitive effort on the design process of evaluation (Be⇆Bs). This suggests that he was using CAD modelling to support conceptual design because it refers to evaluation for reducing uncertainty. The dynamic model analyses also provided empirical evidence of this. A crucial point was reached when designers wanted to shift from sketching to CAD modelling. The contents of the design protocols that occurred at the end of the sketching sessions were examined to identify the factors that triggered this change. One factor was dissatisfaction with the sketches and this turned the CAD design phases into a creative design process. This occurred because dissatisfaction increased the degree of uncertainty at the beginning of the CAD modelling sessions.

4.2 The AMM Study

The aims of the AMM study were to identify the roles of sketching and CAD modelling, to define switching behaviours and to identify which type of switching behaviours could impact on design cognition as well as the creative design process. Six designers participated in a protocol study in which their activities were video recorded. The recordings were coded using the FBS coding scheme. In addition, having completed their tasks, participants reviewed the recordings and were asked to explain their switching behaviours. A three-level coding scheme for analysing switching behaviours was adapted from relevant literature.

4.2.1 The roles of sketching and CAD modelling in the AMM study

Design activity is often viewed as a problem-solving process, containing problem explorations and solution outputs (Dorst & Cross, 2001; Maher & Tang, 2003). Jiang, Gero and Yen (2014) classified FBS design issues into problem spaces and solution spaces. Reasoning about a problem space involves design issues that relate to requirement (R), function (F), and expected behaviour (Be). Reasoning about solution spaces includes behaviours derived from structure (Be) and structure (S). To understand the roles of each design medium in mixed media design environments, the coding structure used for this study was developed so that each segment could be coded into sketching or CAD modelling for the same design issues (e.g. Rs or Rc). Each design session's occurrences of design issues in sketching and CAD modelling were normalised by dividing them by the total number of design issues in that session (Table 4.2). Table 4.2 shows that the lower mean values accompany the lower standard deviations, i.e. the design issue (R). Whereas, the design issues, (Bs) and (S), normally have higher mean values with higher standard deviations.

Table 4.2. Normalised number of design issues and their aggregated distributions (%).

		Participants								
Numbers of design issues		**A**	**B**	**C**	**D**	**E**	**F**	**Mean**	**SD**	**Aggregated (%)**
Sketching	R	4	5	6	3	3	5	4	1.2	4.9
	F	11	6	18	15	3	3	9	6.3	11.1
	Be	12	4	19	16	7	5	11	6.2	13.6
	Bs	21	9	25	43	11	12	20	12.8	24.7
	S	15	19	48	34	37	14	28	13.9	34.6
	D	2	1	4	6	15	27	9	10.1	11.1
CAD modelling	R	0	0	1	0	6	0	1	2.4	0.5
	F	30	18	9	16	2	2	13	10.8	6.1
	Be	45	23	14	11	19	6	20	13.8	9.4
	Bs	97	77	65	48	36	23	58	27.3	27.4
	S	102	103	75	79	96	61	86	17.0	40.6
	D	27	26	59	21	39	36	35	13.7	16.5

Figure 4.9 shows aggregated design issue distributions in sketching and CAD modelling. The six design issue distributions between sketching and CAD modelling have shared a similar pattern. It was noteworthy that the percentages for design issues of requirement (R), function (F), and expected behaviour (Be) in sketching were slightly higher than in CAD modelling. On the other hand, the percentages of design issues of behaviour derived from structure (Bs), structure (S) and design description (D) in CAD modelling were slightly higher than in sketching. In both design media, all participants expended the majority of their cognitive effort reasoning about structure (S) (34.6%~40.6%), followed by the behaviour derived from structure (Bs) (24.7%~27.4%) and then design description (D) (11.1%~16.5%). Much less cognitive effort was spent on the expected behaviour (Be) (9.4%~13.6%), the issues of function (F) (6.1%~11.1%) and requirement (R) (0.5%~4.9%). These trends suggest that participants spent more time solving a problem than in properly framing it. In general,

participants' design issue distributions shared very similar behavioural patterns on both design media. We argue that this is because they facilitated the identification of a problem and the production of a solution and its necessary specifications.

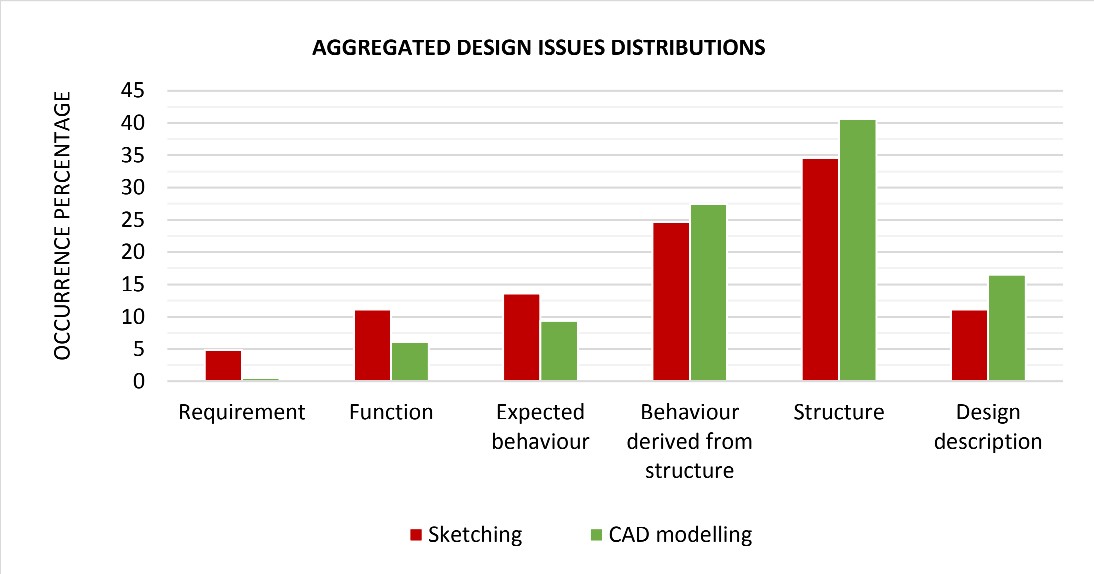


Figure 4.9. Aggregated FBS design issue distributions in sketching and CAD modelling.

Jiang et al. (2014) proposed that a problem-solution (P-S) index is a ratio measurement, computing the ratio of the total occurrences of the design issues concerned with the problem space to the sum of those related to the solution space. They defined that a design session with a P-S index less than or equal to 1 as one with a solution-focused style; whereas a design session with the P-S index value larger than 1 as one with problem-focused style. The Equation (1) shown as follows (Jiang et al., 2014):

$$\text{P-S index} = \frac{\sum(\text{Problem}-\text{related issues})}{\sum(\text{Solution}-\text{related issues})} = \frac{\sum(R,F,Be)}{\sum(Bs,S)} \qquad (1)$$

The values of the P-S index for each participant in sketching and CAD modelling are shown in Table 4.3. The solution-focused style occurred in both sketching and CAD modelling sessions. These results are plotted in Figure 4.10, below a line at the value of 1 for P-S index indicating design activities in mixed media design environments relating to a solution-focused style. CAD modelling sessions had significantly lower P-S index values than sketching sessions, demonstrating a strong tendency of focusing on solution-related issues.

Table 4.3. Values of P-S index.

	Value of P-S index for participants							
Environments	**1. A**	**2. B**	**3 C**	**4. D**	**5. E**	**6. F**	**Mean**	**SD**
Sketching	0.75	0.54	0.59	0.44	0.27	0.50	0.52	0.16
CAD modelling	0.38	0.23	0.17	0.21	0.20	0.10	0.22	0.09

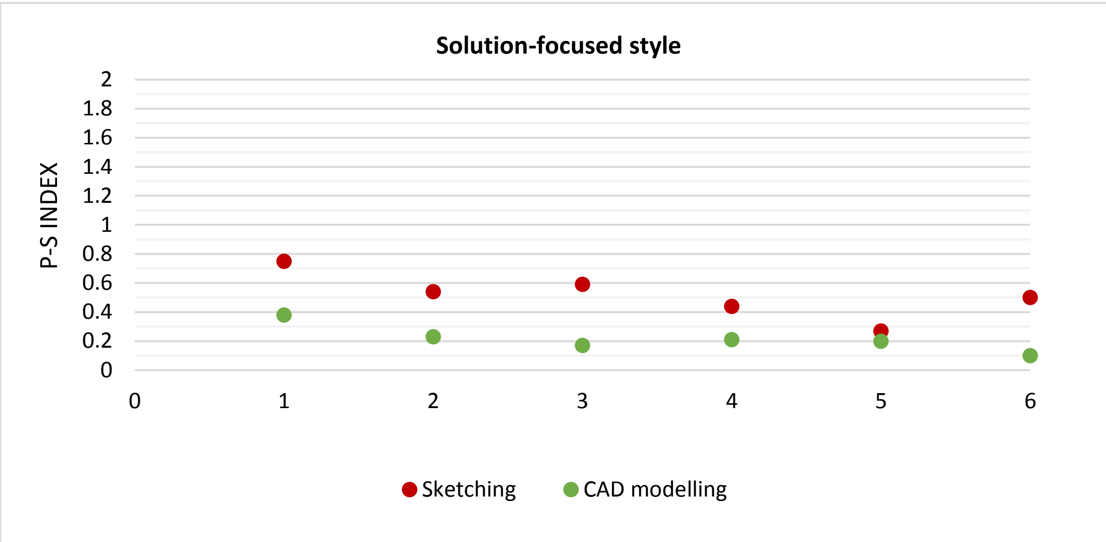


Figure 4.10. Values of P-S index and designing styles.

A syntactic design process is one that presumes all segments are cognitively related to their immediate preceding segment. They are design processes that transform from one segment to the other (Kan & Gero, 2009; Williams et al., 2013). In this study, participants shared a similar design process distribution (Figure 4.11). The majority of time spent was in the design process reformulation I (17.2%~36%) and analysis (16.2%~26.2%), followed by evaluation (8.1%~32.5%) and documentation (4.5%~24.7%). Very little cognitive effort was spent on formulation (0~3.5%).

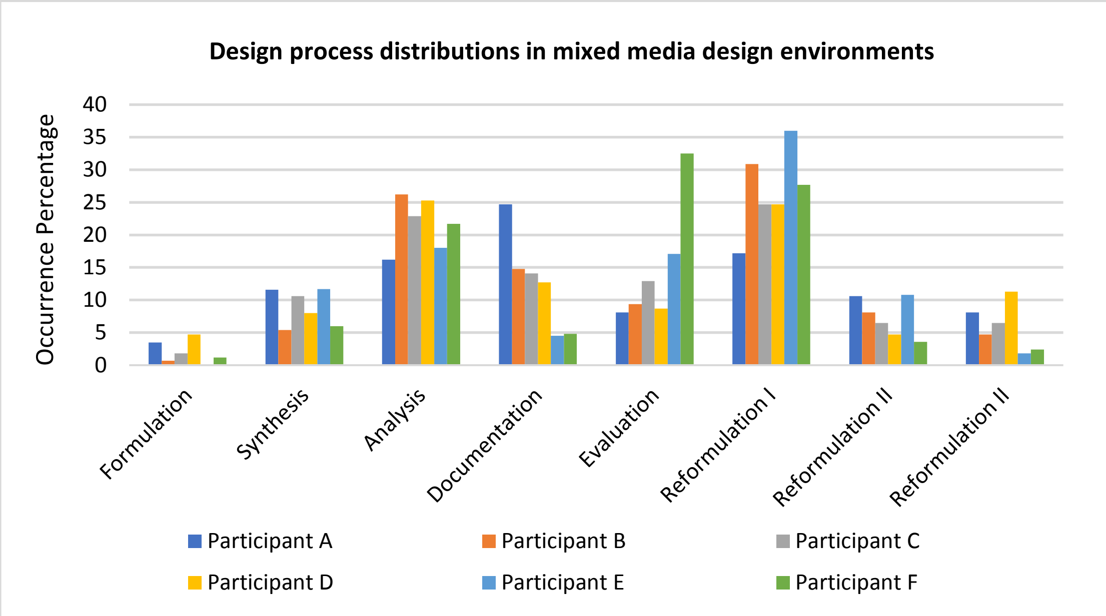


Figure 4.11. Each participant's design process distributions in the AMM design environment.

Although each participant's reasoning process was different, the six participants had very similar patterns of design issue and design process distributions. Both design media therefore appear to serve very similar roles during designing. However, these empirical results differ from Won's comparison study of sketching and CAD modelling. Won's visual thinking study found that roles of design media are different (Won, 2001). The freedom to switch between media may change the roles of sketching and CAD in mixed media environments. The following section explores the reasons for this.

4.2.2 Types of switching behaviours occurring during the design process

The participants switched their design behaviours between ten and twenty times during the data collection activity. Switching from one medium to another is a design process and a physical action involving 'eyes' or 'eyes and hands' movement. Normally, every switch takes a millisecond to accomplish and the participants found it difficult to verbalise their thoughts about this. The think-aloud protocol is limited to capturing what actually happens when participants switch. Therefore, interviews were conducted to explore participants' switching behaviour in detail. These were supplemented with video aids of their design tasks. These switching interviews were transcribed and coded (Table 4.4). Figure 4.12 shows the results.

Table 4.4. Examples of coding switching interviews.

Numbers	Interviews	Codes
11	'Before starting to CAD a new space or idea, I like to check with my drawing in a way. "have I made a good allocation for such a space?" Then continue modelling.'	P-relation
12	'After realising the size of a car the against the building envelope, I returned to sketch to experiment with other possible arrangements for the surrounding spaces.'	E-sketching
13	'I had placed a car in CAD to give me a sense of scale of the garage as a space, I continued sketching to see if the space could be manipulated while still functioning car storage.'	P-visual
14	'I became satisfied with the few initial ideas I had drawn on paper and decided to start modelling them on the computer.'	E-cad
15	'I came across a design issue in CAD, something I thought was going to fit did not, and thus is was back to the drawing board to test new design ideas, and test the sketch in the cad environment'	G-iterations
16	'Design development'	E-sketching

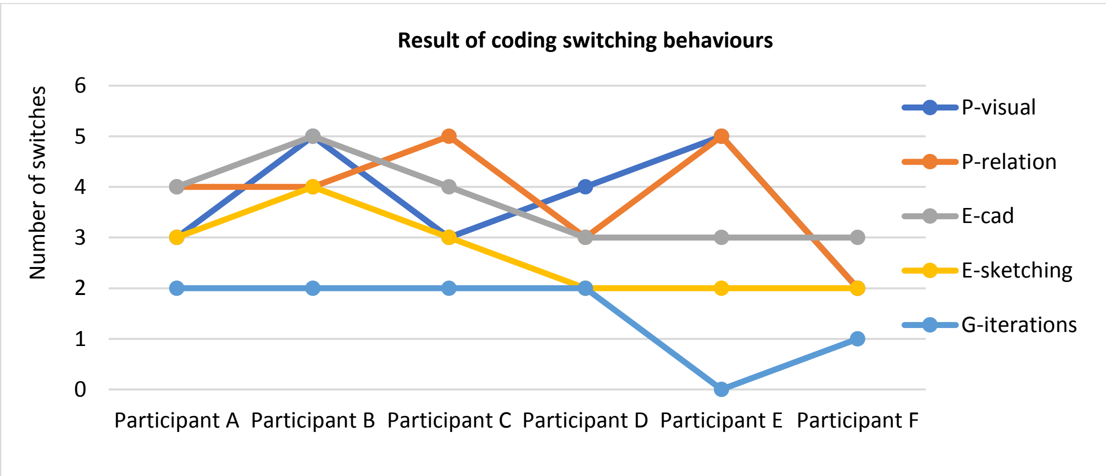
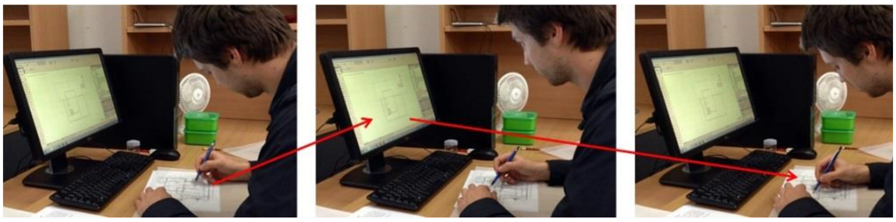


Figure 4.12. Results of coding switching behaviours for participants.

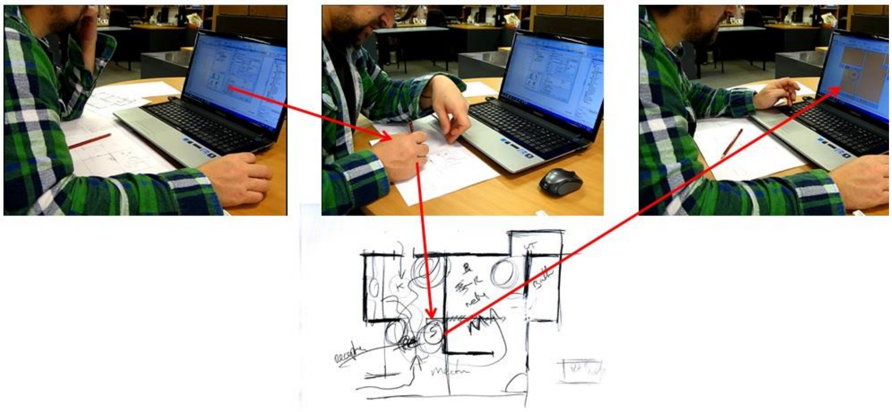
The **perception level** refers to the reasoning process of attending to visual-spatial features of depicted elements on CAD models (such as a sense of scale between objects) or attending to objects/spaces relationships. The CAD model layout and its visualisation were important visual cues for participants to develop designs in sketching. This is defined as P-visual. The sketches of space arrangements that occurred before using CAD helped implement the objects configuration in CAD modelling and allowed comparisons to be made between sketches and models. P-relation refers to this type of eyes' switching. It happens that after long-time CAD modelling, a designer refers to sketches that they have already drawn on paper. Or a designer checks a screen to retrieve CAD model information, such as scale, layout, etc., to explore design alternatives during sketching. In this connection, one participant commented 'Personally, I do like to look at 3D views often when modelling to get a good idea of the project rather than sketching in 3D'. Table 4.5 shows that participants normally use eyes' switching between media to enhance visual-spatial ability.

Table 4.5. Three levels of switching behaviours.

<table>
<tr><th colspan="2">Three levels of switching behaviours</th></tr>
<tr><td>Perception level

Eyes' switching</td><td>
The participant's eyes switched between media to obtain a sense of space scale.</td></tr>
<tr><td>Media level

Single switching</td><td>
Sketching CAD modelling
1. Sketching: After finishing the first-storey CAD models, the participant switched to sketching to quickly explore ideas for the second-storey layout.
2. CAD modelling: An advantage of CAD modelling is that it allows participants to understand different perspectives by rotating or zooming in/out.</td></tr>
<tr><td>Concept level

Integrating switching</td><td>
The participant found it challenging to locate an appropriate place for a stair using CAD. He therefore switched to sketching to refine and evaluate different locations. Once satisfied, the participant transferred the sketches in CAD so the switching was a bridge, linking the idea development process between media.</td></tr>
</table>

The **media level** referred to in Table 4.5 relates to exploring interactions between design media and designers. Participants switched from sketching to CAD or from CAD to sketching (called single switching) because the effectiveness of each design media is different. Sketching allows designers to quickly draw their ideas on paper. Designers then use these drawings to generate alternatives. This activity is called E-sketching. CAD environments offer more detailed and realistic designs providing designers with superior visual feedback. These CAD drawings are accurately dimensioned and to scale. They help designers evaluate the sketches developed earlier. This action is referred to as E-cad. For example, one participant identified the strengths of sketching as follows:

> *'It is certainly quicker and easier to sketch an idea than CAD it up. For instance, a light line on the page may just be a quick idea that ends up getting either forgotten or incorporated into the design by the drawing of progressively heavier lines, whereas… trying to do… similar things with construction lines in a CAD model takes longer, is more to draw, needs to be placed in an actual location (lines are mostly defined by coordinates) and usually needs to be actively deleted to not confuse the resulting design'.*

In contrast, another participant said the following about CAD:

> *'Its strengths are that when one drafts one element, say the location of the wall, a range of other factors are able to be input like wall height, thickness, construction, colour and even cost and more if required... This then means that when one starts drafting the elevation some of the information is already there, and then again, in 3D the form quickly takes shape and can be viewed, checked for element clashes, zoom in and zoom out, and quickly used for perspective view'.*

The **concept level** (Table 4.5) refers to the development of design goals by focusing on one intention/target (e.g. stair design and arrangement) through multiple switches to achieve the desired goal. This often happens when designers review previous drawings and are not satisfied with the outcomes in CAD models. This motivates designers to switch between media for one intonation of one goal (e.g. stair design or bathroom objects/spaces reconfiguration). Taking an example from the experimental data, after completing the ground-level design in CAD, designers switched to sketching to explore alternatives for the first-level design. This is referred to as single switching. However, a designer may not be satisfied with a stair design in sketches and/or CAD models because the stair does not connect two levels and provide good circulation. The designer would then need to go back and forth focusing on stair design to solve this issue. This refers to integrating switching as G-iterations. To illustrate this, one participant said ‘I felt I could achieve better results by sketching back and forth to alter in tandem with the CAD models. I believe it will allow greater conceptual freedom and exploration of ideas’. Additional feedback from another participant was that:

> *‘When designing around the placement of the stairs I found it helpful to reference the sketches I had done earlier. CAD allowed me to quickly operationalise the location of the stair using the original location (in the sketch) as the frame of reference from which I could easily deviate and modify in CAD’.*

These findings match the three types of switching behaviours that have been proposed in the literature review chapter. Table 4.5 shows examples of switching behaviour influencing the design process and changing the roles of sketching and CAD in mixed media design environments.

4.2.3 Summary

The results show that both design media play a very similar design role. Although both media relate to a solution-focused style, when the percentages of FBS design issues were compared, sketching was shown to assist designers in identifying a problem, whereas CAD modelling provided a means to resolve the problem and offer a solution. The results show that switching behaviours supported designers’ perception, media and concept levels during designing as this fits the concept of the 'right tool-right time' (Do, 2005, p. 396). The concept level switching behaviour can integrate two design media into one. This level of switching behaviour has considerable potential to transform the design process into a creative design process, which supports Chen's (2007) findings of using conventional and digital media simultaneously. This involves an iterative switch to explore problems either in the sketching environment or in the CAD modelling environment. Solutions may then be refined using other design environments. Figure 4.13 provides an example of design activities using the AMM approach containing three types of design behaviours.

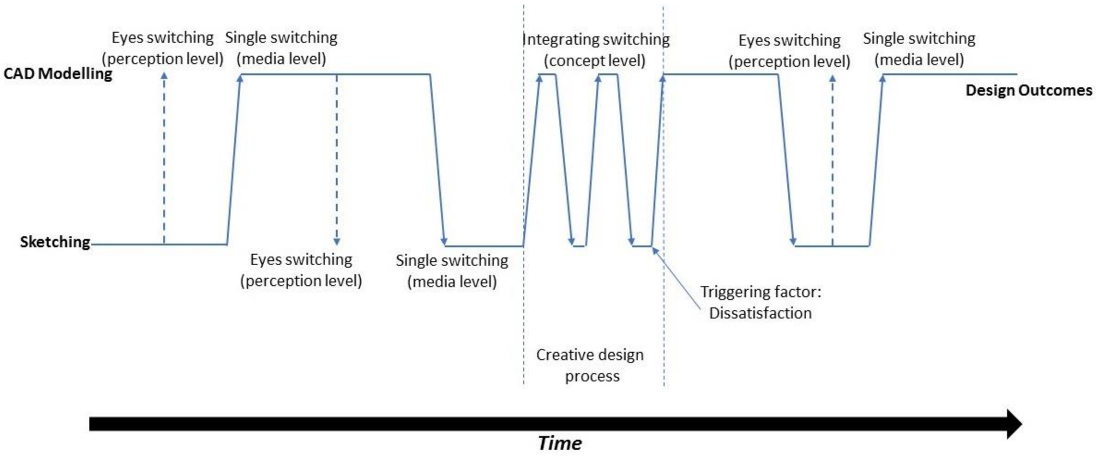


Figure 4.13. An example of design activities using the AMM design approach.

4.3 Comparison of the SMM and AMM Studies

The aims of the comparison study between the SMM and AMM approaches are to determine similarities and differences in the roles of sketching and CAD modelling and to compare the advantages and disadvantages from designers' reflections after using the SMM and AMM approaches. In order to achieve these goals, think-aloud experiments with eight designers were conducted. They were asked to design specific artefacts using two different approaches: firstly, where they were not allowed to switch between media and secondly, where they were allowed to switch. The resulting design activities in these two conditions were compared using the protocol analysis.

4.3.1 Comparison of the roles of sketching and CAD modelling between the SMM and AMM approaches

Each design session's occurrences of design issues using sketching and CAD modelling in SMM and AMM were normalised by dividing them by the total number of design issues in that session (Tables 4.6 and 4.7).

Table 4.6. Normalised number of design issues and their aggregated distributions (%) in SMM.

		Participants in SMM										
Number of design issues		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Mean**	**SD**	**(%)**
Sketching	R	5	2	2	5	3	14	2	0	4	4.3	5.1
	F	5	18	12	9	9	3	1	3	8	5.7	10.3
	Be	16	8	17	8	8	1	4	19	10	6.5	12.8
	Bs	28	20	27	13	16	15	7	36	20	9.5	25.6
	S	29	31	18	19	31	27	22	55	29	11.7	37.2
	D	6	1	8	3	10	21	0	4	7	6.7	8.9
CAD modelling	R	0	1	2	0	0	0	0	0	0	0.7	0
	F	4	10	14	5	1	0	1	0	4	5.2	2.4
	Be	12	15	31	8	9	6	3	14	12	8.6	7.2
	Bs	63	65	103	22	55	24	13	65	51	29.9	30.5
	S	101	118	82	55	88	55	39	73	76	26.3	45.5
	D	15	28	39	7	30	29	10	17	22	11.2	13.1

Table 4.7. Normalised number of design issues and their aggregated distributions (%) in AMM.

		Participants in AMM										
Number of design issues		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Mean**	**SD**	**(%)**
Sketching	R	4	5	6	3	3	5	5	2	4	1.4	5
	F	11	6	18	15	3	3	5	4	8	5.8	10
	Be	12	4	19	16	7	5	10	24	12	7.1	15
	Bs	21	9	25	43	11	12	11	31	20	12.1	25
	S	15	19	48	34	37	14	22	33	28	12.1	35
	D	2	1	4	6	15	27	1	6	8	9	10
CAD modelling	R	0	0	1	0	6	0	0	0	1	2.1	0.1
	F	30	18	9	16	2	2	0	0	10	10.9	5.1
	Be	45	23	14	11	19	6	13	1	17	13.4	8.7
	Bs	97	77	65	48	36	23	37	73	57	25.1	29.2
	S	102	103	75	79	96	61	69	70	82	16.3	42.1
	D	27	26	59	21	39	36	5	17	29	16.2	14.8

All participants had similar aggregated design issue distributions for sketching and CAD modelling in SMM (Figure 4.14) and AMM (Figure 4.15). In both SMM and AMM, it was noteworthy that the percentages for design issues of requirement (R), function (F) and expected behaviour (Be) in sketching were slightly higher than in CAD modelling. In contrast, the percentages of design issues of behaviour derived from structure (Bs), structure (S) and design description (D) in CAD modelling were slightly higher than in sketching. All participants expended the majority of cognitive effort reasoning about structure (S) (SMM: 37.2~45.5%; AMM: 35~42.1%) followed by the behaviour derived from structure (Bs) (SMM: 25.6~30.5%; AMM: 25~29.2%). Much less cognitive effort was spent on issues of function (F) (SMM: 2.4~10.3%; AMM: 5.1~10%) and requirement (R) (SMM: ~5.1%; AMM: 0.1~5%). These trends suggest that participants spent more time solving a problem than in properly framing it. In general, participants' design issue distributions shared very similar behavioural patterns using sketching and CAD modelling.

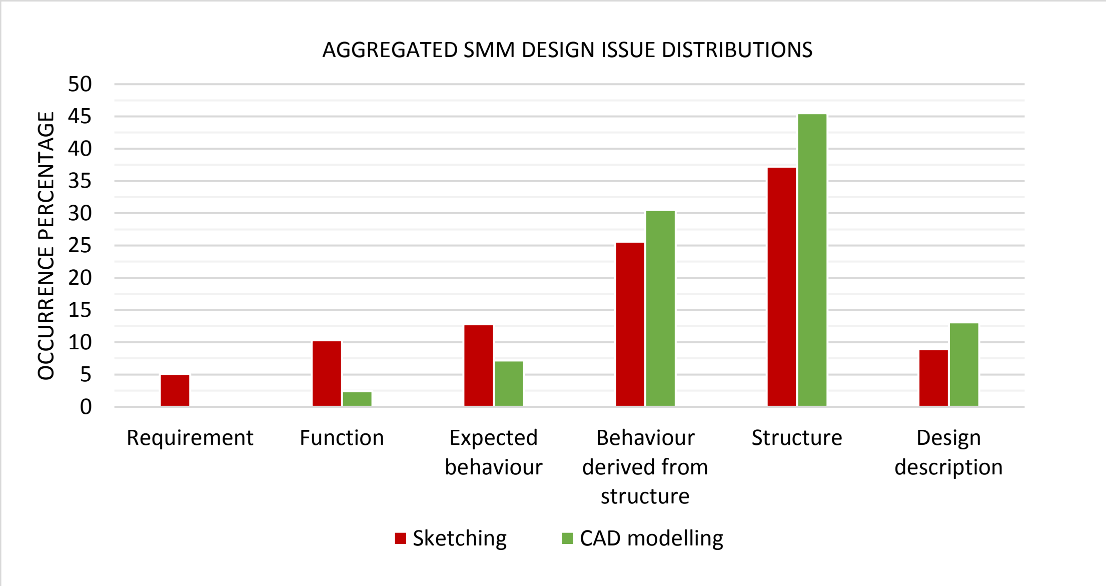


Figure 4.14. Aggregated design issue distributions (%) in the SMM.

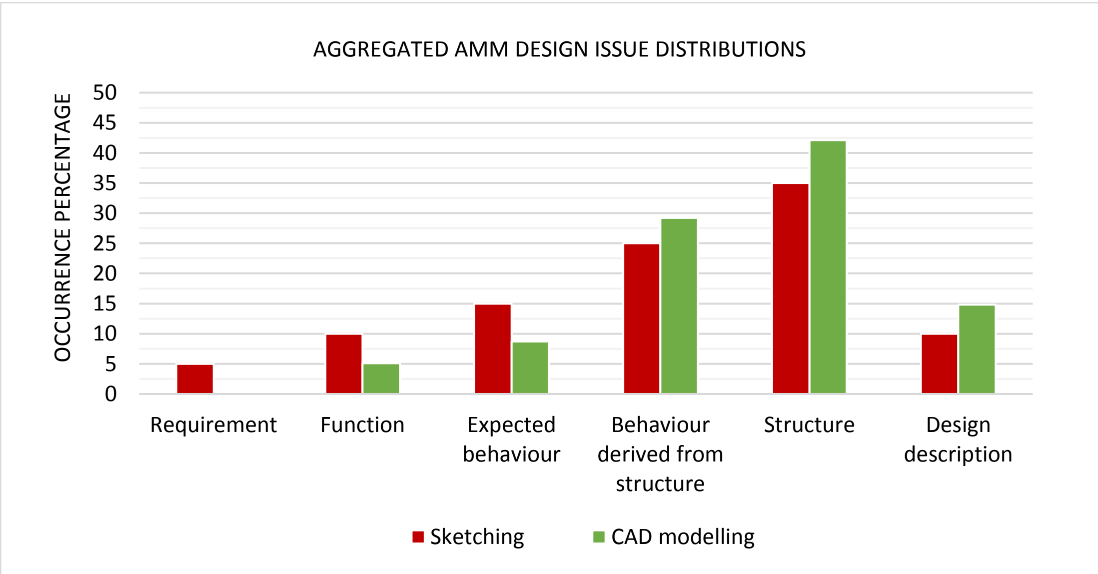


Figure 4.15. Aggregated design issue distributions (%) in the AMM.

Jiang et al. (2014) proposed the problem-solution (P-S) index as a ratio measurement, computing the ratio of the total occurrences of the design issues concerned with the problem space to the sum of those related to the solution space. They argued that a design session with a P-S index less than or equal to 1 was one with a solution-focused style. Whereas, a design session with the P-S index value larger than 1 was one with a problem-focused style. Equation (1) illustrates this (Jiang et al., 2014):

$$\text{P-S index} = \frac{\sum(\text{Problem}-\text{related issues})}{\sum(\text{Solution}-\text{related issues})} = \frac{\sum(R,F,Be)}{\sum(Bs,S)} \qquad (1)$$

The values of the P-S index for each participant using sketching and CAD modelling in SMM are shown in Table 4.8, indicating that a solution-focused style occurred in these sessions. These results are also plotted in Figure 4.16, below a line at the value of 1 for the P-S index, indicating design activities when using sketching and CAD modelling relating to solution-focused style. CAD modelling sessions (Mean: 0.12) had significant lower P-S index values than sketching sessions (Mean: 0.47), demonstrating a strong tendency to focus on solution-related issues.

Table 4.8. Values of P-S index in the SMM.

Value of P-S index for Participants in SMM										
Environments	**1.A**	**2.B**	**3.C**	**4.D**	**5.E**	**6.F**	**7.G**	**8.H**	**Mean**	**SD**
Sketching	0.46	0.55	0.69	0.69	0.43	0.43	0.24	0.24	0.47	0.17
CAD modelling	0.1	0.14	0.25	0.17	0.07	0.08	0.08	0.1	0.12	0.06

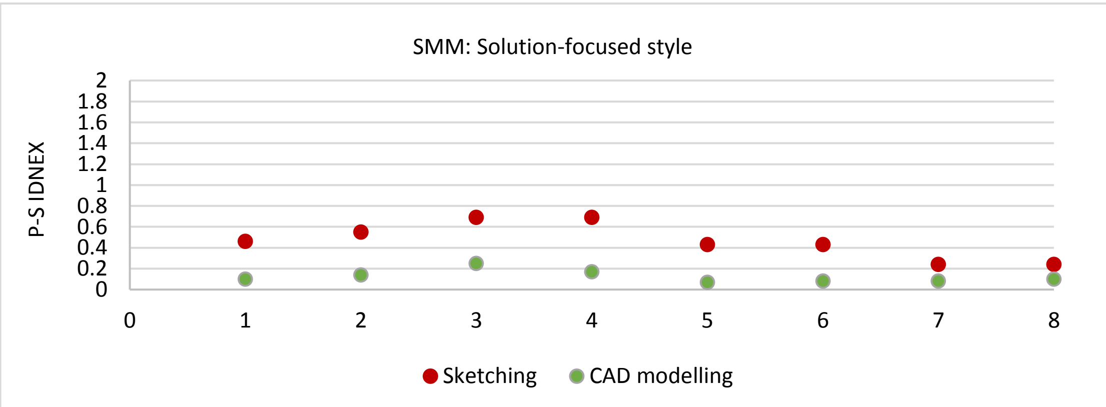


Figure 4.16. Values of P-S index and designing styles in the SMM.

The values of the P-S index for each participant using sketching and CAD modelling in AMM are given in Table 4.9, showing that a solution-focused style occurred in these sessions. The results are also plotted in Figure 4.17, below a line at the value of 1 for the P-S index, indicating design activities when using sketching and CAD modelling relating to solution-focused style. CAD modelling sessions (Mean: 0.18) had significantly lower P-S index values than sketching sessions (Mean: 0.52), demonstrating a strong tendency to focus on solution-related issues. The values of the P-S index in the SMM and AMM were very similar in terms of sketching and CAD modelling.

Table 4.9. Values of the P-S index in the AMM.

Value of P-S index for participants in AMM										
Environments	**1.A**	**2.B**	**3.C**	**4.D**	**5.E**	**6.F**	**7.G**	**8.H**	**Mean**	**SD**
Sketching	0.75	0.54	0.59	0.44	0.27	0.5	0.6	0.47	0.52	0.14
CAD modelling	0.38	0.23	0.17	0.21	0.2	0.1	0.12	0.01	0.18	0.11

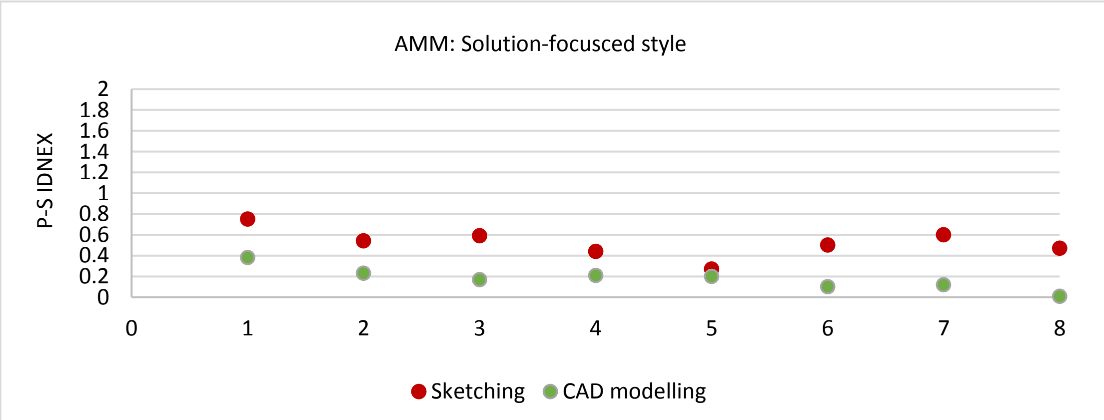


Figure 4.17. Values of the P-S index and designing styles in the AMM.

A syntactic design process is one that presumes all segments are cognitively related to their immediate preceding segment. They are design processes that transform from one segment to the other (Williams, Lee, Gero, & Paretti, 2013). Table 4.10 shows each participant's design process distributions (%) in the SMM and AMM. In this study, participants shared very similar design process distributions in the SMM and AMM (Figure 4.18). The majority of time spent was in the aggregated design processes of reformulation I (SMM: 38.5%; AMM: 28.4%) and analysis (SMM: 22.8%; AMM: 24%), followed by documentation (SMM: 12.1%; AMM: 12.7%) and evaluation (SMM: 9.9%; AMM: 12.1%). Much less cognitive effort was spent on formulation (SMM & AMM: 1.8%).

Table 4.10. Each participant's design process distributions (%) in the SMM and AMM.

Participants' design process distributions (%) in SMM										
	A	B	C	D	E	F	G	H	Mean	SD
Formulation	1.2	1.8	3.7	4.6	2.2	0	0	0.6	1.8	1.7
Synthesis	6.7	6.0	7.9	10.3	7.2	4.4	3.1	6.4	6.5	2.2
Analysis	26.2	24.6	23.2	18.4	25.9	20.0	14.1	30.1	22.8	5.1
Documentation	14.0	8.4	29.3	8.0	6.5	5.6	6.2	19.1	12.1	8.3
Evaluation	4.3	6.0	11.0	6.9	13.7	26.7	4.7	5.8	9.9	7.5
Reformulation I	39.6	43.1	16.5	39.1	36.0	40.0	65.6	28.3	38.5	13.9
Reformulation II	7.9	5.4	3.0	5.7	3.6	1.1	4.7	8.7	5.0	2.5
Reformulation III	0	4.8	5.5	6.9	5.0	2.2	1.6	1.2	3.4	2.5
Participants' design process distributions (%) in AMM										
	A	B	C	D	E	F	G	H	Mean	SD
Formulation	3.5	0.7	1.8	4.7	0	1.2	1.7	0.8	1.8	1.6
Synthesis	11.6	5.4	10.6	8.0	11.7	6.0	9.4	5.7	8.6	2.6
Analysis	16.2	26.2	22.9	25.3	18.0	21.7	22.2	39.8	24.0	7.2
Documentation	24.7	14.8	14.1	12.7	4.5	4.8	11.1	14.6	12.7	6.4
Evaluation	8.1	9.4	12.9	8.7	17.1	32.5	0.9	7.3	12.1	9.5
Reformulation I	17.2	30.9	24.7	24.7	36.0	27.7	45.3	20.3	28.4	9
Reformulation II	10.6	8.1	6.5	4.7	10.8	3.6	9.4	8.9	7.8	2.7
Reformulation III	8.1	4.7	6.5	11.3	1.8	2.4	0	2.4	4.7	3.8

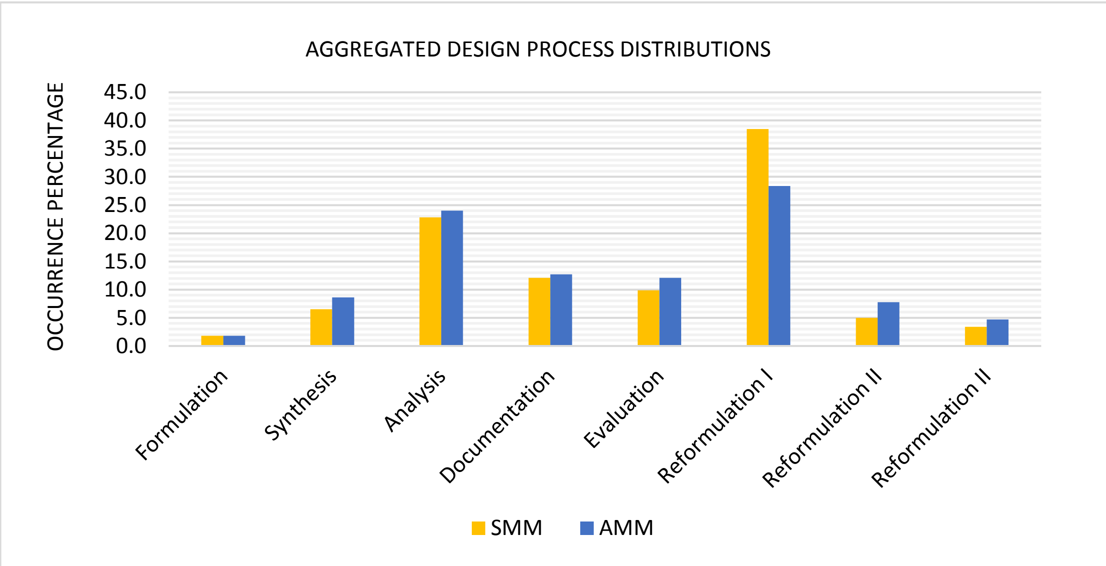


Figure 4.18. Aggregated design process distributions (%) in the SMM and AMM.

Although this study has shown that there were no significant differences between SMM and AMM in terms of design issue distributions, P-S index and design process distributions, it is important to understand participants' reflections on sketching and CAD modelling the design tasks. The following section provides an analysis of these data.

4.3.2 Comparison of designers' reflections after using the SMM and AMM approaches

Although a couple of designers were satisfied with the SMM approach, most felt that it was difficult to complete the tasks without switching between media. During the interviews they identified several drawbacks to the SMM approach. Designers were asked to sketch first, followed by CAD modelling. This resulted in sketching being mainly used for design and CAD modelling being used mainly for documentation. This was mentioned by participant E.

> *'I found this method difficult as it does not suit my natural design behaviour. I felt restricted to the CAD tools available to me, only using them for documentation'. (Participant E)*

Participants C and F argued that CAD modelling could help with some specific design issues while sketches helped in documenting design for a designer's own record.

> *'By restricting the process to the sketching as design and then CAD as documentation only and no allowance to switch between them the capacity of each form is limited. Some design will always happen in the CAD environment, and some documentation (even if only for the designer's own records) will happen best with pencil and paper, so assuming that the division is clear and discreet is wrong. It is generally not possible to memorise a design and then CAD it up correctly, so referring to the sketch is vital'. (Participant C)*

'It did present some difficulties. As a designer one naturally reflects through interacting with representational media. Initially, sketching helps recall and store ideas. Today, as a designer I often sketch, and a lot. The integration with computers and CAD in particular has not been difficult but one establishes workflows that accommodate the new tools such as CAD with sketching and ideation. By isolating the workflow, it made it difficult to quickly switch between ideas and rapidly formulate responses'. (Participant F)

It was felt that by isolating the workflow, CAD modelling becomes less intuitive in terms of idea exploration and slows down the design process (Participants A and B).

'Much more difficult. Without being able to switch it took too long to try different design combinations if the first design didn't fit within the building properly. Then I was left to try to design straight into CAD which is much less intuitive than sketching'. (Participant A)

'I personally found the SMM process more difficult as once I had sketched my ideas and then placed them in CAD I could not sketch further ideas. The problem with SMM is the practitioner needs to 'fix' encountered problems on the screen and not draw by hand possible alternative solutions. This process is much slower then returning to the 'thinking hand' for developing new ideas'. (Participant B)

In addition, participants provided their reflections of the AMM and these have been categorised into two aspects: the roles of design media and switching behaviour, and their merits throughout the design process. Each design media has its advantages and disadvantages. More importantly, the role of switching behaviour is to make use of the advantages from both media, and to use each one to counter the weaknesses of the other. For instance, sketching allows designs to be prepared quickly but is not accurate, while CAD modelling is an accurate means of preparing documentation but is a slow method of preparing designs. Mixed media allows a designer to be fast and accurate, which supports Ibrahim and Rahimian's (2011) and Sachse et al.'s (2001) findings. It is usually faster to brainstorm ideas using sketching, and then easier to change in CAD modelling to see if the ideas work with accurate dimensions. In this connection, a participant said:

> *'I feel that when ideas are more conceptual it is faster and easier to sketch, and when ideas are more developed it is faster and easier to use CAD. I feel that sketching informs the development of an idea that is then drawn in CAD for evaluation, which informs the next round of sketching and so on…. Each medium is useful for different purposes and by using both methods we can get the benefits of speed and conceptual thinking with sketching and also the accuracy and technical resolution of CAD'. (Participant A)*

Participants' observed that mixed media allows one to quickly sketch ideas with a 'thinking hand' and then place those ideas in the digital realm. They observed that once particular ideas are placed on the screen it is quick and easy to manipulate, multiply and distribute them. This is faster than a designer can draw each possible alteration, especially in perspective. This is often compared to a designer mind's eye with the actual 3D computer representation aiding in the design development. For example, a participant said:

> *'The combination of sketching and CAD modelling is beneficial throughout the design process. Personally, I do like to look at a 3D view often when modelling to get a good idea of the project rather than sketching in 3D and that would be a natural way to work for me'. (Participant C)*

Based on these reflections, participants were asked a question: 'Did you feel that switching between media benefited your design?'. The common view was that switching not only allowed for a more accurate testing of conceptual sketches but also allowed designs to grow (having been facilitated by the back and forth feeding of designs). This relates to the concept of the ‘right tool-right time’, (Do, 2005, p. 396) and that such usage would actually engage designers’ thinking along creative pathways. All participants believed strongly that switching between media was an ideal approach for conceptual design. They summarised the contribution of switching as follows:

1. Switching behaviour helps make appropriate design decisions:

   ‘It can make your design flow smoother and allows more design decisions to be made according to the parameters of the CAD application rather than by your own sense of design. For example, one might design a kitchen by what is available in the CAD library rather than designing a kitchen based on your own thinking-hand’.

2. Switching behaviour enhances co-evolution:

   ‘The technique I have found best is to sketch while doing the actual design exploration (being imaginative and thinking about options) and then input the decisions into CAD modelling until things become unsure. At this point I print out the drawings I will find useful (plans sections elevations as appropriate) and sketch over (butter paper or straight on the page) to explore the ideas for resolving the design further. Once I have made some good decisions and am confident of the way forward I go back to the CAD and input the latest ideas by editing and adding to the information there. Then I repeat that process over and over. This way I try to avoid wasting time drafting things that will just need editing/deleting later and also avoid drafting up by hand things that will just have to be drafted again in CAD’.

3. Switching behaviour provides a natural design workflow:

'Many designers use sketching, mostly as visual notes, to rapidly memorise a design idea. CAD is useful to record the ideas and extend the development of the visual notes taken whilst thinking about the design and reflecting upon the design requirements. Using CAD as a permanent record of design ideas that are ever changing on paper helped me stabilise the design workflow. For me personally it was easy and natural to switch between media as it forms a very natural and complementary workflow'.

4.3.3 Summary

The results show that both design media play a very similar design role when using the SMM and AMM approaches. The comparisons indicate that there are more similarities than there are differences in how designers interact with sketches and CAD modelling. The data that were coded during sketching accounted for less than one-third of the total codes in both SMM and AMM sessions because designers spent most of their time working on the CAD models to meet design requirements in terms of functional aspects. However, they may need extra time to focus on aesthetics to achieve the desired outcomes. Participants were subsequently interviewed about each switch and reminded about their design activities using video recordings, and their reflections were collected after finishing design tasks. Six out of eight participants strongly believed that switching behaviour is essential to make use of the advantages from both media, and to use each one to counter the weaknesses of the other. The switching behaviours improve design activities for helping make appropriate design decisions, enhancing co-evolution and providing a natural design workflow. The conclusion of these studies is presented in Chapter 5.

Chapter 5: Conclusion

An analysis of designers' activities using the SMM and AMM approaches were provided in Chapter 4. This final chapter concludes the study and discusses further implications of the research. In order to achieve the aim of this research, the eight research objectives will be verified. Section 5.1 restates the research aim and objectives of this study. Section 5.2 summarises the main findings from three perspectives: the commonalities of using the SMM and AMM approaches, designers' reflections about the two approaches, and the impact of switching behaviour on design cognition. The implications and contributions of the research are presented in section 5.3. Section 5.4 discusses potential future research directions.

5.1 Restate Research Aim and Objectives

5.1.1 Research aim

The aim of this study is to investigate the impact of switching behaviours on designers' cognition and creative design processes (refer to section 1.2.1).

5.1.2 Research objectives

The aim of this research has been achieved because the following research objects were completed (refer to section 1.2.1.1):

1. To develop a framework of mixed media that involves switches between design media;

   Research objective 1 was achieved by identifying a research gap in mixed media design environments; this was discussed in Chapters 2 and 3, and reported in Papers One and Two. On top of that Paper One reviews the FBS coding scheme to examine design activities and switching behaviours, while Paper Two suggests that a switching behaviour coding scheme should be developed and content-oriented to analyse switching interviews.

2. To conduct a pilot study;

   Research objective 2 was achieved. The outcome of the pilot study was reported in

Paper Three (Chapter 3). Paper Four expands Paper Three to solidify the preliminary outcomes.

3. To explore the factors that triggered change in the roles of CAD modelling in the SMM study;

   Research objective 3 was achieved. From empirical evidence, dissatisfaction is confirmed as a triggering factor for changing the roles of CAD modelling in the SMM design environment. It was referred to in Chapter 4 section 4.1, and reported in Paper Five.

4. To identify the roles of sketching and CAD modelling in the AMM study;

   Research objective 4 was achieved. From empirical evidence, both sketching and CAD modelling plays a markedly similar role in the AMM design environment. It was discussed in Chapter 4 section 4.2, and reported in Paper Six.

5. To develop definitions for different types of switching behaviours in the AMM study;

   Research objective 5 was achieved. Based on the literature review the three types of switching behaviours are: eyes' switching, single switching, and integrated switching. Their definitions were provided in Chapter 2 section 2.4 and included in Paper Six.

6. To identify which type of switching behaviours can support on design cognition as well as the creative design process in the AMM study;

   Research objective 6 was achieved. These switching behaviours appropriately supported designers in perception, media and concept levels in the design process. The concept level switching behaviour can integrate two design media into one. This level of switching behaviour has considerable potential to transform the design process into a creative design process. It was discussed in Chapter 4 section 4.2, and reported in Paper Six.

7. To determine similarities and differences in the roles of sketching and CAD modelling when using the SMM and AMM approaches;

Research objective 7 was achieved. Based on three assessments of design issue distributions, problem-solving index and design process distributions, the results show that there is no significant difference between sketching and CAD modelling between the SMM and AMM. It was discussed in Chapter 4 section 4.3, and reported in Paper Seven.

8. To compare the advantages and disadvantages from designers' reflections after using the SMM and AMM approaches.

   Research objective 8 was achieved. The results show that advantages of using the AMM approach over the SMM approach because: switching behaviours benefit design activities, helps make appropriate design decisions, enhances co-evolution, and provides a natural design workflow. It was discussed in Chapter 4 section 4.3, and reported in Paper Seven.

5.2 Key Findings of the Study

This study set out to explore the impact of switching behaviour on designers' cognition. To achieve this, a protocol study was conducted to collect empirical data from eight designers using the SMM approach and the AMM approach. Two types of coding schemes (process-oriented and content-oriented) capable of examining the roles of sketching and CAD modelling (in both SMM and AMM) and switching behaviours (in the AMM) were developed. Applying the research method of protocol analysis, the roles of sketching and CAD modelling using both approaches were identified. Through a series of data analyses, three main findings have been identified: (1) the commonalities of using the SMM and AMM approaches; (2) designers' reflections about the two approaches; and (3) impact of switching behaviour on design cognition.

5.2.1 The commonalities of using the SMM and AMM approaches

Three design briefs with similar challenges were randomly assigned to eight designers through a protocol study. The aggregated data collected from this study were coded and those relating to sketching accounted for less than one-third of total codes in both the SMM (78/245) and AMM (80/275) sessions. This was because designers spent most of their time working on the CAD models to meet design requirements. The data were analysed using the FBS coding scheme, revealing that the roles of sketching and CAD modelling were very similar for these two approaches during the design processes. The three assessments using the FBS coding scheme were: design issue distributions, problem-solution (P-S) index, and design process distributions.

1. In both SMM and AMM sessions, all participants shared similar design issue distributions for sketching and CAD modelling. They expended the majority of their cognitive effort reasoning about structure (S) followed by the behaviour derived from structure (Bs). Much less cognitive effort was spent on issues of function (F) and requirement (R). From the results of using both approaches, sketching was shown to assist designers in identifying a problem (as higher percentages of R, F & Be were apparent), whereas CAD modelling provided a means to resolve the problem and offered a solution (as higher percentage of Bs and S were apparent).
2. The values of the P-S index in SMM and AMM sessions were very similar, relating to a solution-focused style. CAD modelling sessions had significantly lower P-S index values than sketching sessions, demonstrating a strong tendency to focus on solution-related design issues.
3. The design process distributions in both sessions were very similar. The majority of time spent was in the aggregated FBS design processes of reformulation I and analysis, followed by documentation and evaluation. Much less cognitive effort was spent on formulation.

When coded using the FBS scheme, it was difficult to distinguish between data representing sketching and CAD modelling using the SMM and AMM approaches. Although the results indicated that the roles of sketching and CAD modelling were very similar (based on the FBS coding scheme), designers' reflections about the two approaches were very different, which will be explained in next section.

5.2.2 Designers' reflections on sketching and CAD modelling

Designers' reflections about the two approaches were very different. They experienced several difficulties using the SMM approach. For example, a participant said:

> *'It did present some difficulties. As a designer one naturally reflects through interacting with representational media. Initially sketching helps recall and store ideas. Today, as a designer I often sketch, and a lot. The integration with computers and CAD in particular has not been difficult but one establishes workflows that accommodate the new tools such as CAD with sketching and ideation. By isolating the workflow, it made it difficult (to) quickly switch between ideas and rapidly formulate responses'.*

There were also some drawbacks using CAD modelling after sketching (without switching), which is primarily documentation. The SMM approach is not a natural design behaviour as it slows down the design process. Most designers preferred to sketch ideas on paper and test them in a CAD environment. If they experienced design problems using CAD, they sketched alternate ideas and then tested them using CAD. In the SMM exercises, participants had to resolve all the problems they encountered on the screen without reverting to sketches.

Using CAD modelling for design rather than for generating documentation may be seen as beneficial. Protocol data indicated that being dissatisfied with sketching outcomes allowed designers to expend cognitive effort on evaluating design alternatives during their CAD design activities. Dissatisfaction is a triggering factor to change the roles of CAD modelling.

In addition, participants identified several benefits during the AMM design process as follows:

> *'I feel that when ideas are more conceptual it is faster and easier to sketch, and when ideas are more developed it is faster and easier to use CAD. I feel that sketching informs the development of an idea that is then drawn in CAD for evaluation, which informs the next round of sketching and so on…. Each medium is useful for different purposes and by using both methods we can get the benefits of speed and conceptual thinking with sketching and also the accuracy and technical resolution of CAD'.*

The results of using the AMM approach confirmed that the role of switching behaviour is to make use of the advantages from both media, and to use each one to counter the weaknesses of the other. For instance, sketching allows designs to be prepared quickly but is not accurate, while CAD modelling is an accurate means of preparing documentation but is a slow method of preparing designs. Mixed media allows a designer be fast and accurate, which supports Ibrahim and Rahimian's (2011) and Sachse et al.'s (2001) findings. It is usually faster to brainstorm ideas using sketching, and then easier to change these designs using CAD to see if the ideas work with accurate dimensions. Furthermore, 3D modelling allows changes to be visualised almost instantly.

Based on these reflections, participants were asked: 'Did you feel that switching between media benefited your design?*'* The common view was that switching not only allowed for a more accurate testing of conceptual sketches but also allowed designs to grow (having been facilitated by the back and forth feeding of designs). This relates to the concept of the 'right tool-right time', (Do, 2005, p. 396) and that such usage would actually engage designers' thinking along creative pathways. All participants believed strongly that switching between media was an ideal approach for conceptual design. They summarised the contribution of switching as follows:

1. Switching behaviour helps make appropriate design decisions:

'It can make your design flow smoother and allows more design decisions to be made according to the parameters of the CAD application rather than by your own sense of design. For example, one might design a kitchen by what is available in the CAD library rather than designing a kitchen based on your own thinking-hand'.

2. Switching behaviour enhances co-evolution:

'*The technique I have found best is to sketch while doing the actual design exploration (being imaginative and thinking about options etc.) and then input the decisions into CAD modelling until things become unsure. At this point I print out the drawings I will find useful (plans sections elevations as appropriate) and sketch over (butter paper or straight on the page) to explore the ideas for resolving the design further. Once I have made some good decisions and am confident of the way forward I go back to the CAD and input the latest ideas by editing and adding to the information there. Then I repeat that process over and over. This way I try to avoid wasting time drafting things that will just need editing/deleting later and also avoid drafting up by hand things that will just have to be drafted again in CAD*'.

3. Switching behaviour is a natural design workflow:

'Many designers use sketching, mostly as visual notes, to rapidly memorise a design idea. CAD is useful to record the ideas and extend the development of the visual notes taken whilst thinking about the design and reflecting upon the design requirements. Using CAD as a permanent record of design ideas that are ever changing on paper helped me stabilise the design workflow. For me personally it was easy and natural to switch between mediums as it forms a very natural and complementary workflow'.

5.2.3 The impact of switching behaviours on design cognition

The results of this study show that switching behaviours supported designers' perceptions, media and concept levels during their design activities. This fits the concept of the 'right tool-right time' (Do, 2005, p. 396). The **perception level** refers to the reasoning process of attending to visual-spatial features of depicted elements on CAD models (such as a sense of scale between objects) or attending to objects/spaces relationships. The CAD model layout and its visualisation were important visual cues for participants and assisted them in developing designs in sketching. The sketches of space arrangements produced before using CAD helped implement the object's configuration in CAD and allowed comparisons to be made between sketches and models.

The **media level** relates to exploring interactions between design media and designers. Participants switched from sketching to CAD or from CAD to sketching because the effectiveness of each design medium is different. Sketching allows designers to quickly draw their ideas on paper. These drawings can then be used to generate alternatives. CAD environments offer more detailed and realistic designs, providing designers with superior visual feedback. These CAD drawings are accurately dimensioned and to scale. They help designers evaluate the sketches developed earlier.

One participant identified the strengths of sketching as follows:

> *'It is certainly quicker and easier to sketch an idea than CAD it up. For instance, a light line on the page may just be a quick idea that ends up getting either forgotten or incorporated into the design by the drawing of progressively heavier lines, whereas… trying to do… similar things with construction lines in a CAD model takes longer, is more to draw, needs to be placed in an actual location (lines are mostly defined by coordinates) and usually needs to be actively deleted to not confuse the resulting design'.*

In contrast, another participant said the following about CAD:

> *'Its strengths are that when one drafts one element, say the location of the wall, a range of other factors are able to be input like wall height, thickness, construction, colour and even cost and more if required... This then means that when one starts drafting the elevation some of the information is already there, and then again, in 3D the form quickly takes shape and can be viewed, checked for element clashes, zoom in and zoom out, and quickly used for perspective view'.*

The **concept level** refers to the development of design goals by focusing on one intention/target (e.g. stair design and arrangement) through multiple switches to achieve the desired goal. This often happens when designers review previous drawings and are not satisfied with the outcomes in CAD models. This motivates them to switch between media for one iteration of one goal (e.g. stair design or bathroom objects/spaces reconfiguration). As an example, after completion of the ground-level design in CAD, designers switched to sketching to explore alternatives for the first-level design. However, a designer may not be satisfied with a stair design in sketches and/or CAD models because the stair may not connect two levels and provide good circulation. The designer would then need to go back and forth focusing on stair design to solve this issue. This confirmed that dissatisfaction is the triggering factor for designers to switch between media.

To illustrate this, one participant said:

> *'I felt I could achieve better results by sketching back and forth to alter in tandem with the CAD models. I believe it will allow greater conceptual freedom and exploration of ideas'. Additional feedback from another participant was that: 'When designing around the placement of the stairs I found it helpful to reference the sketches I had done earlier. CAD allowed me to quickly operationalise the location of the stair using*

the original location (in the sketch) as the frame of reference from which I could easily deviate and modify in CAD'.

5.3 Further Implications for Design

Although the development of new design media/software could help a designer accomplish a desired outcome, they may need training to manipulate such new design media. The framework of this research is to purpose a new way of using available design media (i.e. sketching and CAD modelling) involving switching behaviours to offer the advantages of mixed media design environments. The implications of this study include design practice and design education. One of the contributions from this study is to explore ideal approaches of using mixed media. After conducting a serious of experiments, the findings of this study are shown in the following:

1. The empirical evidence collected from the SMM study in Chapter 4 shows that dissatisfaction with sketches resulted in the entire CAD design phase becoming uncertain. Thus, an optimal solution may not be achieved by using one design medium. This means that subsequent design sessions need to support designers to refine their prior designs by evaluating alternatives. If designers prefer to use the SMM approach, this study has demonstrated that CAD modelling could well support their conceptual design phase if they are unsatisfied with prior sketching outcomes because each design media has its advantages and disadvantages.
2. Based on the literature review, an alternative approach of using mixed media (AMM) involving switching behaviour was proposed in Chapter 2. The results show that although both sketching and CAD modelling play a very similar design role, switching behaviours can support designers' perceptions, media and concept levels during designing. The concept level switching behaviour can integrate two design media into one. This level of switching behaviour has considerable potential

to transform the design process into a creative design process, which supports Chen's (2007) findings of using conventional and digital media simultaneously. This involves iterative switches to explore problems either in the sketching environment or in the CAD modelling environment. Solutions may then be refined using other design environments. These findings suggest how educational programs about design (such as sketching and CAD modelling programs) integrate into one program to enhance the three levels of designers' cognition in the design process. For instance, a boundary of site plans or a part of buildings can be modelled at the beginning of the design phase so students/designers can print them as a reference (e.g. accurate proportion) to help sketch different solutions/layouts rather than using a pen from scratch. This also means that during the different design stages of design project courses (e.g. concept design stage, detailed design stage and final design stage), students should be encouraged to use the AMM approach instead of the limitations of using design media in the different design stages so switching behaviours can support students' design cognition as well as design processes.

5.4 Future Research

Based on this mixed media study, there are several points that warrant future research. These include: experiment timeline, design brief refinement, and gender balance of participants.

5.4.1 Experiment timeline

The data that were coded during sketching accounted for less than one-third of the total codes in both SMM and AMM sessions because designers spent most of their time working on the CAD models to meet design requirements in terms of functional aspects. They needed extra time to focus on aesthetics to achieve the desired outcomes. Doubling working time may be appropriate for further mixed media studies.

5.4.2 Design brief refinement

Although all participants were satisfied with the design requirements, most designers focused on the functional aspect of building design and less on aesthetics to achieve the desired outcomes. Although the design briefs included both aesthetic and functional requirements, most designers did not pay attention to the appearance of the building design. Thus two types of design briefs are recommended for further studies using the AMM approach: aesthetics-oriented and function-oriented. This may help explore designers' preferences of using sketching and/or CAD modelling to achieve different oriented design briefs.

5.4.3 Gender balance of participants

This study involved eight participants, including six male designers and two female designers. Although all participants performed ten to twenty switches between media, the reflections of different genders were different. The six male designers strongly believed that the benefits of using AMM outweighed the benefits of using SMM. However, the two female designers did not feel that there was a strong difference between using these two approaches. Although the results of this study were generated by eight designers, future research may consider gender balance and increase the sample size to obtain robust results.

References

Aliakseyeu, D. (2003). A Computer Support Tool for the Early Stages of Architectural Design. PhD thesis, Eindhoven University of Technology, The Netherlands.

Aish, R. (1986). Three-dimensional input and visualization, *Computer-Aided Architectural Design Futures, CAAD Futures Conference Proceedings* 68-84.

Akin, O. (1993). Architects' reasoning with structures and functions, environment and planning B: *Planning and Design*, 20, 273-294.

Akin, Ö. & H. Moustapha (2004). Strategic use of representation in architectural massing, *Design Studies*, 25(1), 31-50.

Akintoye, A., Goulding, J. & Zawdie, G. (2012). Construction Innovation and Process Improvement, Wiley & Sons, New York, NY.

Ball, L. J., Ormerod, T. C. & Morley, N. J. (2004). Spontaneous analogizing in engineering design: A comparative analysis of experts and novices. *Design Studies,* 25 495-508.

Beheshti, R. (1993). Design decisions and uncertainty. *Design Studies*, 14 (1) 85-95.

Bilda, Z. & Demirkan, H. (2003). An insight on designers' sketching activities in traditional versus digital media. *Design Studies,* 24(1), 27-50.

Bilda, Z. & Gero, J. S. (2007). The impact of working memoery limitations on the design process during conceptualization. *Design Studies*, 28, 343-367.

Bilda, Z., Gero, J. S. & Purcell, T. (2006). To sketch or not to sketch? That is the question. *Design Studies*, 27(5) 587-613.

Bouchlaghem, D., Shang, H., Whyte, J. & Ganah, A. (2005). Visualisation in architecture, engineeering and construction (AEC). *Automation in Construction*, 14 287-295.

Buhl, H. (1960). *Creative engineering design.* Iowa State University, Iowa.

Candy, Z. Bilda, Z., Maher, M. L. & Gero, J. S. (2004). Evaluating software support for video data capture and analysis in collaborative design studies, *Proceedings of QualIT04 (Qualitative Research in IT and IT in Qualitative Research) Conference,* Brisbane, Australia.

Candy, L. & Edmonds, E. (1996). Creative design of the Lotus bicycle. *Design Studies*, 17(1) 71-90.

Chen, Z. R. (2007). How to improve creativity: Can designers improve their design creativity by using conventional and digital media simultaneously? *CAAD Futures 2007, Proceedings of the 12th International CAAD Futures Conference* 571-583.

Collier, E. & Fischer, M. (1995). Four-Dimensional Modeling in Design and Construction. Technical Report, Nr. 101, CIFE, Stanford.

Cross, N. (2001). Achieving pleasure from purpose: The methods of Kenneth Grange, Product Designer. *Design Journal*, 4(1) 48-58.

Cross, N. (1999). Natural Intelligence in Design, *Design Studies*, 20 25-29.

Cross, N. & Cross, A. (1995). Observations of teamwork and social processes in design, *Design Studies*, 16(2) 143-170.

Cross, N. & Dorst, K. (1999). Co-evolution of Problem and Solution Space in Creative Design, in J. S. Gero and M.L. Maher (eds.) *Computational Models of Creative Design IV, Key Centre of Design Computing*, University of Sydney, 243-262.

Cross, N., Christiaans, H. & Dorst, K. (1996). Analysing design activity, *Wiley & Sons*, New York, NY.

Christensen, B. T. & Schunn, C. D. (2009). The role and impact of mental simulation in design. *Applied Cognitive Psychology*, 23 327-344.

Dorst, K. (1996). The Design Problem and its Structure, in N. Cross, H. Christianns and K. Dorst (eds.), *Analysing Design Activity, John Wiley & Sons Ltd*, Chichester, New York, 17-35.

Do, E. & Gross, M. (1995). Sketching Analogies: Finding Visual References by Sketching, Computing in Design - Enabling, Capturing and Sharing Ideas, *ACADIA Conference Proceedings*, 35-52.

Dorst, K. & Cross, N. (2001). Creativity in the design process: Co-evolution of problem–solution. *Design Studies*, 22(5) 425–437.

Dorst, K. & Dijkhuis, J. (1995). Comparing paradigms for describing design activity, *Design Studies*, 16(2) 261-275.

Dorst, K. (1996). The design problem and its structure, in N. Cross, H. Christianns and K. Dorst (eds.), *Analysing Design Activity, Chichester and New York: John Wiley*, 17-35.

Do Y.-L. (2005). Design Sketches and Sketch Design Tools, in KBS - *Knowledge Based Systems* (18) 383-405

Eastman, C., Teicholz, P., Sacks, R. & Liston, K. (2011). BIM handbook: a guide to building information modelling for owners, managers, designers, engineers and contractors. *Wiley*.

Eckersley, M. (1988). The form of design process: a protocol analysis study, *Design Studies*, 16, 86-94.

Elsas P. A. & van, Vergeest, J. S. M. (1998). New functionality for computer aided conceptual design: the displacement feature. *Design Studies*, 19 (1) 81–102.

Ericsson, K. A. & Simon, H. A. (1993). Protocol Analysis: Verbal Reports as Data MA, *MIT Press*, Cambridge

French, M. (1985). Conceptual design for engineers. *The Design Council,* London.

Gero, J. S. (1990). Design prototypes: A knowledge representation schema for design. *AI Magazine*, 11(4) 26-36.

Gero, J. S. & Kannengiesser, U. (2014). The Function-Behaviour-Structure ontology of design, in Amaresh Chakrabarti and Lucienne Blessing (eds), *An Anthology of Theories and Models of Design*, Springer, pp. 263-283.

Gero, J. S. & Maher, M. L. (1993). Modelling Creativity and Knowledge-Based Creative Design, *Lawrence Erlbum Associates*, Hillsdale, New Jersey, USA.

Gero, J. S. & Maher, M. L. (1991). Mutation and analogy to support creativity in computer-aided design, in G. N. Schmitt (ed.), *CAAD Futures '91*, ETH, Zurich, pp. 241-249.

Gero, J. S. & McNeill, T. (1998). An approach to the analysis of design protocols, *Design Studies* 19(1) 21-61.

Gero, J. S., Jiang, H. & Williams, C. B. (2012). Does using different concept generation techniques change the design cognition of design students? *ASME IDETC* DETC2012-71165.

Gero, J. S., Kan, J. W. T. & Pourmohamadi, M. (2011). Analysing design protocols: Development of methods and tools. *In International Conference on Research into Design*, Indian Institute of Science Bangalore, India.

Gero, J. S. & Sudweeks, F. (1998). Artificial Intelligence in *Design '98*, Dordrecht: Kluwer.

Gero, J. S. & Tang, H. H. (2001). The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of design protocols. *Design Studies* 19(1) 21-61.

Goldschmidt, G. (1997). Capturing indeterminism: Representation in the design problem space, *Design Studies* 18(4), 441–445.

Goldschmidt, G. (2003). Cognitive economy in design reasoning, in Lindemann, U. (ed.) *Human Behaviour in Design*, Springer Verlag, Berlin, 53–62.

Goldschmidt, G. (1992). Criteria for design evaluation: a process–oriented paradigm, in YE Kalay (ed.), *Evaluating and Predicting Design Performance*, John Wiley & Son, Inc., New York, 67–79.

Goldschmidt, G. (1994). On visual design thinking: the Vis kids of architecture. *Design Studies* 15(2), 158-174.

Goldschmidt, G. (1990). Linkography: assessing design productivity. *Cyberbetics and System '90*, Singapore.

Goldschmidt, G. (1991). The dialectics of sketching, *Creativity Research Journal* 4(2), 123–

143.

Goldschmidt, G. (1995). Visual displays for design: Imagery, analogy and databases of visual images, in Koutamanis, A., Timmermans, H. and Vermeulen, A. (eds), *Visual Databases in Architecture*, Aldershot, Avebury, 53–74.

Goulding, J. S., Rahimian, F. P. & Wang, X. (2014). Virtual reality-based cloud BIM platform for integrated AEC projects. *Journal of Information Technology in Construction* (ITCON), 19 (Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends) 308-325.

Guyton-Simmons, J. & Ehrmin, J. T. (1994). Problem solving in pain management by expert intensive care nurses. *Critical Care Nature*, 14 37-44.

Hales, C. (1993). Managing engineering design. Longman Scientific and Technical, England, Harlow.

Hanna, R. & Barber, T. (2001). An inquiry into computer in design: Attitudes before - attitudes after, *Design Studies* 22, 255-281.

Ho, T.-F. (2006). The Spatial Interpretation of Freehand Sketches: Using Programming and Rapid Prototyping, the National Chia Tung University.

Ibrahim, R. & Rahimian, F. P. (2010). Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction,* 19(8) 978-987.

Isaksen, S. G., Dorval, K. B. & Treffinger, D. J. (1994). Creative approaches to problem solving. Kendall Hunt Publishing Co., Dubuque, Iowa.

Jiang, H. & Yen, C. (2009). Protocol analysis in design research: A review. *In the International Association of Societies of Design Research (IASDR) 2009 Conference* 147-157.

Jiang, H, Gero, J. S. & Yen, C. C. (2014). Exploring designing styles using problem-solution indexes. *in* JS Gero (ed), *Design Computing and Cognition'12,* Springer, pp. 85-101.

Kan, J. W. T. & Gero, J. S. (2009). A generic tool to study human design activity, *in* R Noell Bergendahl, M, Grimheden, M, Leifer, L, Skogstad, P and Badke-Schaub, P (eds), *Human Behavior in Design,* Design Society 123-134.

Kan, J. W. T. & Gero, J. S. (2005). Can entropy indicate the richness of idea generation in team designing? *Proceedings of the 10th International Conference on Computer Aided Architectural Design Research in Asia (CAADRIA 2005)*, New Delhi, India.

Kan, J. W. T. & Gero, J. S. (2007). Can an objective measurement of design protocols reflect the quality of a design outcome? *Internatinal conference on Engineering design (ICED 2007)*, Paris, France.

Kan, J. W. T. & Gero, J. S. (2008). Acquiring information from linkography in protocol studies of designing. *Design Studies*, 29(4), 315-337.

Kan, J. W. T. & Gero, J. S. (2008). Do computer mediated tools affect team design creativity? *Proceedings of the 13th International Conference on Computer Aided Architectural Design Research in Asia(CAADRIA 2008)*, Chiang Mai, Thailand.

Kavakli, M. & Gero, J. S. (2001). Sketching as mental imagery processing. *Design Studies*, 22(4), 347-364.

Kan, J. W. T. & Gero, J. S. (2005). Can entropy indicate the richness of idea generation in team designing? *Proceedings of the 10th International Conference on Computer Aided Architectural Design Research in Asia (CAADRIA 2005)*, New Delhi, India.

Kim, M. J. & Maher, M. L. (2005). Creative Design and Spatial Cognition in a Tangible User Interface Environment. *Computational and Cognitive Models of Creative Design VI, J. Gero and M. L. Maher,* University of Sydney, 233-250.

Kim, M. J. & Maher, M. L. (2008). The impact of tangible user interfaces on spatial cognition during collaborative design. *Design Studies*, 29(3), 222-253.

Kolodner, J. L. (1994). From natural language understanding of case-based reasoning and beyond: A perspective on the cognitive model that ties it all together. In Langer, E., and Schank, R. C. (Eds.), Beliefs, *Reasoning and Decision Making: Psycho-Logic in Honor of Bob Abelson*, Lawrence Erlbaum Associates, Inc., Northvale, NJ. 55-110.

Lawson, B. (2004). What designers know, Architectural Press, Boston, MA.

Lawson, B. (2006). How Designers Think, Architectural Press, Boston, MA.

Lewis, R. & Sequin, C. (1998). Generation of 3D building models from 2D architectural plans, *Computer-Aided Design*, 30(10), 765-779.

Lin, C. (2003). Seeing Moving Seeing Model for Computer Media, *8th International Conference on Computer Aided Architectural Design Research in Asia.*

Lin, C. Y. (2001). A digital procedure of building construction, *in Gero, J., Chase, S. and Rosenman, M. (eds), CAADRIA2001, Key Centre of Design Computing and Cognition,* University of Sydney, 459-468.

Linstone, H. A. & Turoff, M. (1975). The Delphi Method; Techniques and Applications, Addison-Wesley, Reading Massachusetts.

Lloyd, P., Lawson, B. & Scott, P. (1995). Can concurrent verbalisation reveal design cognition? *Design Studies* 16: 237–259.

Madrzo, L. (1999). Types and instances: A paradigm for teaching design with computers, *Design Studies*, 20(2) 177-194.

Maher, M. L. Poon, J. & Boulanger, S. (1996). Formalizing design exploration as co-evolution: A combine general approach. In J. S. Gero & F. Sudweeks (Ed.), *Advances in Formal Design Method for CAD*. London, England.

Maher, M. L. & Poon, J. (1996). Modelling design exploration as co-evolution. *Microcomputers in Civil Engineering.* 11(3), 195-209.

Maher, M. L. & Tang, H. H. (2003). Coevolution as a computational and cognitive model of design. *Research in Engineering Design*, 14(1), 47–63.

Mitchell, W. (1998). Articulate Design of Free-Form Structure, *Proceeding of AI in structural Engineering 1998*, 223-234.

McNeill, T., Gero, J. S. & Warren, J. (1998). Understanding conceptual electronic design using protocol analysis, *Research in Engineering Design* 10(3) 129-140.

Newell, A. (1990). Unified theories of cognition. Cambridge, Mass: Harvard University Press.

Oxman, R. (2000). Design media for the cognitive designer. *Automation in Construction*, 9(4), 337-346.

Oxman, R. (2006). Theory and design in the first digital age, *Design Studies*, 27(3), 229-265.

Paletz, S. B. F. & Peng, K. (2009). Problem finding and contradiction: Examining the relationship between naïve dialectical thinking, Ethnicity, and Creativity. *Creativity Research Journal*, 21, 139-151.

Pahl, G. & Beitz, W. (1996). Engineering Design: A Systematic Approach, 2ND ed., Springer-Verlag, London, UK.

Purcell, T. & Gero, J. S. (1998). Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology, *Design Studies* 19(4) 389-430.

Purcell, T., Gero, J., Edward, H. & McNeil, T. (1994). The Data in Design Protocols: The Issue of Data Coding, Data Analysis in the Development of Models of the Design Process, in N. Cross and H. Christiaans.

Rahimian, R. F., Ibrahim, R. & Jaffar, F. Z. (2008). Feasibility study on developing 3D sketching in virtual reality (VR) environment. *ALAM CIPTA, Int. J. Susta. Trop. Des. Res. Pract,* 3, 60-78.

Reffat, R. (2002). Three-dimensional CAD Models: Integrating Design and Construction, in R. Best and G. de Valence (eds), *Innovation in Design and Construction: Building in Value*, Butterworth Heinemann, Oxford, 291-305.

Robbins, E. (1994). Why Architects Draw, MIT Press, Cambridge.

Romer, A., Pache, M., Weißhahn, G., Lindemann, U. & Hacker, W. (2001). Effort-saving product representations in design-results of a questionnaire survey. *Design Studies*, 22(6) 473-491.

Sachse, P. Leinert, S. & Hacker, W. (2001). Designing with computer and sketches, *Swiss Journal of Psychology*, 60(2) 65-72.

Salman, H. (2011). The impact of CAAD on design methodology and visual thinking in architectural education. (PhD thesis) Robert Gordon University.

Salman, H., Laing, R. & Conniff, A. (2014). The impact of computer aided architectural design programs on conceptual design in an educational context. *Design Studies*, 35 (4) 412-439.

Schon, D. A. (1983). The Reflective Practitioner, Harper Collins, New York.

Schön, D. A. (1992). Designing as Reflective Conversation with the Materials of a Design Situation, *Knowledge-Based System*, (5.1), 3-14.

Schon, D. A. & Wiggins, G. (1992). Kinds of seeing and their functions in designing, *Design Studies*, 13(2), 135-156.

Schunn, C. D. & Trafton, J. G. (2012). The psychology of uncertainty in scientific data analysis. In G. Feist and M. Gorman (Eds.), Handbook of the Psychology of Science. New York, NY: Springer Publishing, pp. 461-483.

Scrivener, S. A. R. & Clark, S. M. (1994). Sketching in collaborative design in L MacDonald, L. and Vince, J. (eds) *Interacting with virtual environments*, Wiley, Chichester, UK.

Shih, Y. T., Sher, D. W. & Taylor, M. (2015). Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers. *International Journal of Architectural Research*, volume 9, issue 3.

Simon, H. A. (1983). Search and reasoning in problem solving, *Artificial Intelligence*, 21. 7-29.

Sobek II, D. K. & Jain, V. K. (2004). Two instruments for assessing design outcomes of capstone projects, *Proceeding of the 2004 American Society for Engineering Education Conference and Exposition.*

Suwa, M., Purcell, T. & Gero, J. (1998). Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies*, 19, 455-483.

Suwa, M. & Tversky, B. (2001). How Do Designers Shift Their Focus of Attention in Their Own Sketches? In Anderson, M., Meyer, B. and Olivier, P. (eds.) *Diagrammatic Reasoning and Representation*, Berlin: Springer, 241-260.

Suwa, M. & Tversky, B. (1996). What Architects See in Their Design Sketches: Implications for Design Tools, *the Conference on Human Factors in Computing Systems (CHI'99)*, 191-192.

Suwa, M. & Tversky, B. (1997). What do architects and students perceive in their design sketches? A protocol analysis, *Design Studies*, 18(4), 385-403.

Suwa, M., Purcell, T. & Gero, J. S. (1999). Unexpected Discoveries: How Designers Discover Hidden Features in Sketch, in J.S. Gero and B Tversky (eds.) *Visual and Spatial Reasoning in Design*, Key Centre of Design Computing and Cognition, University of Sydney, 145-162.

Suwa, M., Gero, J. & Purcell, T. (2000). Unexpected discoveries of design requirements: important vehicles for a design process, *Design Studies*, 21(4), 539–567.

Szalapaj, P. (2001). CAD Principles for Architectural Design, Architectural Press, Oxford.

Tang, H. H. & Gero, J. S. (2001). Cognition-based CAAD, in B de Vries, J van Leeuwen and H Achten (eds), *CAADFutures 2001*, Kluwer, Dordrecht 523-531.

Tang, H. H. & Gero, J. S. (2001). Sketches as affordances of meanings in the design process, in JS Gero, B Tversky and T Purcell (eds), *Visual and spatial reasoning in Design II*, Key centre of design computing and cognition, University of Sydney, Sydney 271-282.

Tang, H. H. Lee, Y. Y. & Gero, J. S. (2011). Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the Function-Behaviour-Structure coding scheme. *Design Studies*, 32(1) 1-29.

Tracey, M. W. & Hutchinson, A. (2016). Uncertainty, reflection, and designer identify development. *Design Studies*, 42 86-109.

Ullman, D. G., Wood, S. & Craig, D. (1990). The importance of drawing in the mechanical design process. *Computers & Graphics*, 14(2), 263-274.

van der Lugt, R. (2005). How sketching can affect the idea generation process in design group meetings. *Design Studies*, 26(2), 101-122.

van Elsas, P. & Vergeest, J. (1998). New functionality for computer-aided conceptual design: the displacement feature, *Design Studies*, 19 (1) (1998), 81-102.

Van Someren, M. W., Barnard, Y. F. & Sandberth, J. A. C. (1994). The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes. London: Academic Press.

Verstijnen, I. M. Hennessey, J. M. Leeuwen, C. van Hamel, R. & Goldschmidt, G. (1998). Sketching and creative discovery. *Design Studies*, 19 (4) 519–546.

Vermaas, P.E. & Dorst, C. H. (2007). On the Conceptual Framework of John Gero’s FBS Model and the Prescriptive Aims of Design Methodology. *Design studies* 28 133-157.

Visser, W. (1992). Designers' Activities Examined at Three Levels: Organisation, Strategies and Problem-Solving Processes, *Knowledge-Based System*, 5(1), 92-104.

Yamamoto,Y., Nakakoji, K. and Takada, S. (2000). Hands-on representations in a two-dimensional space for early stages of design, *Knowledge Based Systems* 13(6), 374–384.

Williams, C. B., Lee, Y., Gero, J. S. & Paretti, M. (2013). Exploring the effect of the design prompt on students' design cognition, *ASME IDETC2013 DETC2013*.

Wiltschnig, S., Christensen, B. T. & Ball, L. J. (2013). Collaborative problem-solution co-evolution in creative design. *Design Studies*, 34 (5), 515-542.

Won, P. H. (2001). The comparison between visual thinking using computer and conventional media in the concept generation stages of design. *Automation in Construction*, 10(3), 319-325.

PART II

THIS PART INCLUDES SEVEN PAPERS:

P 1. Shih, Y. T., Williams, A. & Gu, N. (2011) A method to investigate differences of sketching before and during CAD modelling design process. *Proceedings of the 2011 International Conference of the Association of Architecture Schools of Australia (AASA 2011)*, Geelong, Australia, pp. 308-318 (ISBN 978-0-9581925-5-2)

P 2. Shih, Y. T., Williams, A., Gu, N. & Lee, J. H. (2011) A switching coding scheme for exploring design cognition in mixed media design environments. *Proceedings of the 45th Conference of the Australian and New Zealand Architectural Science Association (ANZAScA 2011)*, Sydney, Australia, (ISBN 978-0-9581221-3-9)

P 3. Shih, Y. T., Sher, D. W. & Taylor, M. (2013) Using FBS ontology to analyse and compare designers' reasoning processes in SMM and AMM design environments: A pilot study with architectural designers. M. A. Schnabel and J-Y Tsou (eds.), *Cutting Edge in Architectural Science: Proceedings of the 47th International Conference of the Architectural Science Association (ASA) 2013*, Hong Kong, pp 123-132 (ISBN 978-0-9923835-0-3)

P 4. Shih, Y. T., Sher, D. W. & Taylor, M. (2015) Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers. *International Journal of Architectural Research*, volume 9, issue 3 (Scopus)

P 5. Shih, Y. T., Sher, D. W. & Taylor, M. (2017) The roles of design media for teaching architectural design. *Journal of Architectural and Planning Research* (SSCI) (under review)

P 6. Shih, Y. T., Sher, D. W. & Taylor, M. (2017) Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes. *Design Studies* (SCI) (In press)

P 7. Shih, Y. T., Sher, D. W. & Taylor, M. (2017) A comparison of designers' reflections of designing using sketching and CAD modelling. *Research in Engineering Design* (SCI) (with editor)

A METHOD TO INVESTIGATE DIFFERENCES OF SKETCHING BEFORE AND DURING CAD MODELLING PROCESS

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ABSTRACT

Previous research, such as Sachse et al's (2001), adopted traditional sketching in the CAD modelling process and this method improved the design quality. However, there has been little investigated from a cognitive perspective of using mixed media. Mixed media design environments consist of conventional and digital tools, which are often superior to an individual tool during the conceptual design phase (Ibrahim and Rahimian, 2010). When designers switch media from sketching to CAD modelling, the action of shifting is believed to improve design creativity (Chen, 2007). In studies of mixed media (Ibrahim and Rahimian, 2010; Chen, 2007), designers were asked to use sketching first followed by CAD modelling. This method of using mixed media involving one shift in media is called sequential mixed media (SMM). However, there is an alternative method of using mixed media, known as alternate mixed media (AMM), in which designers alternate freely between sketching and CAD modelling. There has been limited studies in exploring designers' behaviours in AMM, their shifting actions between tools and the triggering factors initiating the shifting actions. The paper provides a comprehensive analysis of a wide variety of design tools supporting conceptual design in the early design process. The paper also presents a methodology for a future study to investigate design cognition in mixed media design environments. The outcomes of the proposed research will lead to a more critical understanding of the way of using both design tools so that they can be utilised more effectively. The proposed research will particularly answer why and when designers shift from one tool to another tool during the conceptual design phase.

Keywords: Mixed media, Protocol analysis, Design cognition, FBS model

INTRODUCTION

There are several studies of the impact of different types of design media, such as using the diverse solo design tools (Aliakseyeu et al., 2006, Gu et al., 2011, Schweikardt and Gross, 2000), comparing two solo design tools (Sachse et al., 2001, Won, 2001, Kim and Maher, 2008), and comparing solo and mixed design environments (Ibrahim and Pour Rahimian, 2011). Sachse et al (2001) studied on more than 100 expert engineering designers utilising sketching before and during CAD modelling. Their study identied results such as an improvement in the quality of solutions, reduction in the time taken to complete tasks and the number of processing steps required in achieving the CAD model. Their approach to studying the designers involved in sketching and CAD modelling was through a questionnaires survey, the participants' cognitive processes were not considered in the study and it did not therefore address the issues of understanding the changing from sketching to CAD had on design behaviours or the implications of using sketching before and during CAD. The research project reported in this paper uses these studies as a starting point for studying the design activity where mixed media is employed and the cognitive processes which underpin it.

The aim of this paper is to report on the rationale for the application of a coding scheme for studying the design process and strategies in design cognition in mixed media environments including Function-Behaviour-Structure (FBS) model (Gero, 1990). This paper adapts them to suit the context of the use of sketching and CAD modelling to understand designers' behavioural changes when utilising mixed media environments and, further, to identify the triggering factors which initiate shifting between the tools. The paper also reports on the findings of an analysis of the rationale for a designer's utilisation of external tools, and why there is a need to understand the use of mixed media. The paper will also develop a rationale for the use of protocol analysis as the appropriate method for studying the design situation related to the application of the chosen coding scheme. The purpose of the study proposed in the paper is to provide a better understanding of the impact of using mixed media and the differences between SMM and AMM upon designers.

WHY INVOLVE CAD MODELLING IN THE EARLY DESIGN PHASE

Computer-Aided-Design (CAD) was first developed in the 1960's and has progressed to become an important tool supporting the design processes (McFadzeam, 1999). Although CAD modelling can be considered to fulfil a similar role in design to that of word processors for writing (van Dijk, 1995). The different roles and relationship between CAD modelling and sketching are not well understood (Kiviniemi and Penttilä, 1995). The environment of mouse, keyboard and the screen is dissimilar to that of the pencil and paper. These different design environments can pose difficulties due to no direct physical connection in between hands and eyes (Ekelund et al., 1992). Another difficulty, posed, is the transfer of the final design from sketching to CAD modelling (Herbert, 1993). In sketching, the design drawing is done on the paper simultaneously with the design thinking but CAD modelling builds 3D model through 2D layout, perspective, and other detail section views (Haapasalo, 1997). The outcomes of design are often represented as several drawings or one CAD modelling of the building that is done in real scale (Penz, 1992). The early conceptual design phase may also involve CAD modelling in this case the subsequent design phases may include such activities as detail design which only requires small scale modification of CAD modelling.

Design Tool Studies

Previous research which identifies the implication of using such design tools is reported below (Table 1). The early design process involves many cognitive activities including the organisation of ideas to find a solution. This organisation involves both synthesis and analysis of a variety of perspectives and requirements. Many designers use “visual thinking” utilising external aids to better understand an idea through sketching (Laseau, 1989). This iterative method of testing ideas and informing the design phase through the use of images directs and aids the designers’ decision making. Sketching provides a way to store the conceptual ideas so designers can revisit (Ullman et al., 1990). “Seeing-as” and “seeing-that” modes were observed among architectural students when they generated ambiguous sketching (Goldschmidt, 1994). Design can be considered as a “conversation” with materials via sketching and highly dependent on seeing, according to “seeing–moving–seeing” model (Schon and Wiggins, 1992). Sketching provides representations of design solutions that allow for a variety of interpretations and sequential decisions (Scrivener and Clark, 1994). Schon’s concept infers that a reflective conversation is where the designer ‘seeing what is there, drawing in relation to it, seeing what is drawn’ and so further progressing the design. Therefore, one of the most important tools that designers have at their disposal during the early design stage is sketching; however, other design tools such as digital sketching are not yet significant but pose possibilities for the future (Tang et al., 2011). Table 1 below provides a summary of what has been learned thus far about the role of single medium’s implications upon the design activity.

Table 1: Types of Solo Design Tools

Type 1: Sketching (Pencil and Paper)
‘Seeing-as’ and ‘seeing-that’ modes were developed by observing architectural students generating unclear and ambiguous sketches. Sketching is a significant element of design creativity during the design stages. A designer frequently uses sketching as descriptions for the objects to be designed that is called interactive imagery (Goldschmidt, 1994). In addition, designing as a conversation with materials is via sketching and importantly dependent on seeing. They described the functions of different types of seeing in designers'

“moves” as “seeing–moving–seeing” (Schon and Wiggins, 1992).
Type 2: Digital Sketching (Sketch Tablet & Tangible User Interfaces (TUIs))
Instead of trying to replace such conventional ways of sketching, it is considered to try and maintain the strengths of these conventional ways of working while at the same time improving them by providing access to new media. They discuss the realisation of a tool for conceptual architectural design on an existing augmented reality (AR) system, called the “Visual Interaction Platform” (Aliakseyeu et al., 2006).
Type 3: 3D Virtual Worlds and TUIs
The problem they found that many design projects occur at the same times but in different locations. Thus, they conducted two protocol experiments on design collaboration: remote design collaboration and co-located collaboration with tangible user interfaces (TUIs). The former study is to understand the behavioural changes in situations that are physically remote but co-located in 3D models virtually. The result of the latter study shows that designers’ cognitions can be improved when using TUIs combined with augmented reality (AR) (Gu et al., 2011).
Type 4: Digital Clay
They present Digital Clay, a working prototype of sketching recognition program that interprets gestural and abstract sketching and constructs appropriate three dimensional digital models (Schweikardt and Gross, 2000).
Type 5: CAD Modelling
The result shows that CAD can fulfil the same role for sketching as word processors for writing. However, at the moment CAD is still in the “typewriter” era. CAD should advance with intuitive user interfaces supporting hand movements, to better support design (van Dijk, 1995).

Whereas Table 2 shows that designers utilising sketching have better synthesis strategies than using CAD modelling (Bilda and Demirkan, 2003; Stones and Cassidy, 2007), Overall they have no significant differences. Thus, both sketching and CAD modelling can be used during the early design stages.

Table 2: Comparing Two Solo Design Tools

Type 1: Sketching VS. CAD Modelling
When designers use conventional media to generate concepts, their cognitive behaviours are simpler than those when using computer tools (Won, 2001).
Type 2: Sketching VS. Digital Sketching
The result shows that the design processes using traditional and digital sketching are not statistically different (Tang et al., 2011).
Type 3: TUIs VS. Graphic User Interfaces (GUIs)
The main problem of GUIs is that designers cannot design intuitively because they have to interact via a keyboard and mouse. The result reveals that the use of TUIs changes designers' spatial cognition and improves their problem finding behaviours (Kim and Maher, 2008).

Reported in Table 3 is that mixed media is potentially superior to the solo media outlined above in Table 1 and Table 2. Huang and Lee (2004) in a comparison of two types of mixed media found that using digital sketching with CAD modelling simultaneously, the designer can maintain the same cognitive behaviours in sketching while performing CAD modelling.

Table 3: Comparing Solo Design Tools and Mixed Media Design Environments

Type 1: Sketching VS. Mixed Media VS. CAD Modelling
Results show that for designers, using mixed media is superior to using sketching or CAD modelling only. They recommend a VR-based alternative design interface that would improve design representation, hence, enhance cognition and communication among novice designers during the conceptual design phase (Ibrahim and Pour Rahimian, 2011).
Type 2: Sketching and CAD Modelling VS. Digital Sketching and CAD Modelling
They develop a new formula for employing digital media in design, which supports 2D sketches and computer models simultaneously. In this scenario, the designer can maintain cognitive behaviours in sketching while constructing computer models (Huang and Lee, 2004).
Type 3: Haptic CAD Modelling & Digital Sketching VS. Physical Modelling & Sketching
Traditional tools (freehand sketching and mock-up tools) and haptic devices with tangible interfaces were compared in terms of novice designers’ spatial cognition. In brief, the main findings show significant improvement in designers’ spatial cognition within the haptic

devices with tangible interfaces. However, this device is expensive and many designers have no experience in such design media (Rahimian and Ibrahim, 2011).
Type 4: Sketching VS. Mixed Media VS. CAD Modelling
Chen's studies graphic design when using conventional and digital media simultaneously and found design creativity occurs when shifting media (Chen, 2007).

Why Study Mixed Media Design Environments

The most appropriate two design tools to form a mixed media design environments are sketching and CAD modelling. Romer et al. (2001) surveyed 106 designers for "how often do you use…?" and '"what do you use…for?" in terms of sketching, prototyping and CAD modelling. The results identified that traditional sketching is the most popular design tool; however, though not to a significant degree over CAD modelling. In addition, the traditional sketching is used significantly for solution development, supporting design memory and communication; while, CAD modelling is used significantly for solution development, testing solutions, documentation, and supporting communication.

To date there has not been significant efforts made to understand the use of these media in conjunction with each other. Many architects still prefer to use paper and pen or scale models in the early design stage (Gross and Do, 1996). These design tools offer the required flexibility, speed and intuitive interaction to achieve efficient design outcomes. However, the tendency is for designers to transfer their sketching into CAD modelling thus causing an interruption in their design process flow. Therefore, in order to reduce the time spent on the transition from the early design stage to more precise stages, more and more architects start to use digital design software, likes AutoCAD, ArchiCAD and other design programs. Thus, using sketching and CAD modelling together is one of main methods which assists designers work intuitively while digitising.

RESEARCH METHODS FOR EXPLORING DESIGN COGNITION IN MIXED MEDIA DESIGN ENVIRONMENTS

Table 4 documents the range of research methods employed so as to better understand designers' behaviours whilst utilising these external aids. Protocol analysis has been utilised to understand the difference between novice and expert designers, to study design strategies (Stones and Cassidy, 2007), and to compare traditional and digital sketching (Tang et al., 2011). Protocol Analysis is a methodology which often use the "think aloud" approach to documenting and analysing a designer's decision making processes, it is an ethnographic approach to capturing and analysing thought processes as they inform the physical actions of the designer. The behaviours and the "spoken" thought processes are then encoded against a predetermined coding scheme, the protocol analysis coding strings can then be analysed statistically using such methods as an ANOVA to understand the design process as well as evaluate design outcomes (Sachse et al., 2001, Ibrahim and Pour Rahimain, 2011). The literature summarised in Table 4 below supports the application of Protocol Analysis as an appropriate methodology to assist in better understanding the impact that mixed media would have on designers' behaviours.

Table 4: Types of the Research Methods

Method 1: Protocol Analysis	
(Tang et al., 2011)	Subjects: novice designers Coding scheme: adapted from Gero's FBS model Design media: traditional and digital sketching
Method 2: Combined Protocol Analysis with ANOVA	
(Sachse et al., 2001)	Subjects: novice designers Evaluation criteria: six types of physical operation steps Design media: CAD modelling and CAD modelling with sketching
Method 3: Combined Protocol Analysis with Linkograph	
(Goldschmidt, 1990)	Post Protocol Analysis, every pair of design moves in a given sequence of moves is checked for the existence of links, which are then notated in a graph called Linkograph.
Method 4: Combined Questionnaire Survey with SPSS	
(Römer et al., 2001)	200 questionnaires were posted to designers, 106 completed questionnaires were sent back. Then the questionnaire data was analysed by employing descriptive statistics.

A Rationale for Developing Shifting Behaviour Coding Scheme Based on Gero's FBS Model

Designing is a purposeful action involving thinking, evaluation, and decision making. External tools such as sketching and CAD modelling enhance more detailed problem analysis, solution generation, evaluation, and documentation (Romer et al., 2001, Sachse et al., 1999). Gero (1990) devised a design prototype called Function-Behaviour-Structure

(FBS) model to retrieve design process and information. FBS model consists of six categories: requirements(R), function (F), expected behaviour (Be), structural behaviour (Bs), structure (S), and description (D). The designers switching from one tool to another, in mixed media design environments, has been difficult to code. Therefore, we develop Switch Behaviour Coding Scheme based on Gero's FBS model to encode designers' switches from sketching to CAD modelling (SK>CAD) and switches from CAD modelling to sketching (CAD>SK). Interviews with the designers can be used to obtain the triggering factors for every switching action (Table 5).

Table 5: Shifting Behaviour Coding Scheme

Categories	Descriptions
(SK>CAD)	Switching action from sketching to CAD modelling
(CAD>SK)	Switching action from CAD modelling to sketching

Understanding the Design Strategies in Mixed Media Design Environments

Table 6 lists eight design processes or strategies from FBS model: formulation, synthesis, analysis, evaluation, documentation and reformulation (Gero et al., 2011). Through Protocol Analysis by applying the above Shifting Behaviour Coding Scheme, we can have a better understanding about designers' switching actions in Mixed Media Design Environments and their trigger factors. Also, we can clearly identify which tool enhances problem-finding or problem-solving through Gero's notions of design strategies using FBS model.

Table 6: Defining Design Strategies Using FBS Model (Gero et al., 2011)

Design strategies	Descriptions
Formulation	Formulation which transforms a function or functions into a set of expected behaviours (F>Be).
Synthesis	Synthesis, where a structure is proposed to fulfil the expected behaviours (Be>S).
Analysis	An analysis of the structure produces a derived behaviour (S>Bs).

Evaluation	An evaluation process acts between the expected behaviour and the behaviour derived from the structure (Be>Bs and Bs>Be).
Documentation	Documentation, which produces the design or partial design descriptions (S>D).
Reformulation 1	Reformulation of the structure (S>S).
Reformulation 2	Reformulation of the expected behaviour (S>Be).
Reformulation 3	Reformulation of the function (S>F).

CONCLUSION: FUTURE WORK

The design activity is increasingly being influenced by the introduction of new technologies, invariably these technologies may extend beyond mere support of the design process as we currently know it and may invariably influence the process itself. This influence may be enhancement but it may also limit or constrain design. It is therefore important to have an understanding of the impact of the new technologies on design and to extend this understanding to how and when in the design process would they be most effective. Also having an appreciation of any negative or limiting effect of technologies may have because of the potential to distract from the cognitive processes rather than the support of the cognitive processes of design.

This paper identifies a gap in our understanding of the impact of mixed media design environments that integrate digital technologies i.e. CAD modelling with traditional modes of design i.e. sketching. Our existing understanding would indicate that is the potential to enhance the utilisation of these design media in an integrated approach rather than simply sketching preceding design documentation using CAD. What is proposed by the paper is that through the application of the research methodology of Protocol Analysis that we may gain an appreciation of how these two modes of design environments may be better utilised to support the design process. Though this paper precedes the instigation of the research it does provide an appreciation of the need and an approach to gain a better understanding of the application of tradition and current technology to the support of the design process. Such understanding is very important for contemporary architectural design education to better teach digital design in architecture schools and to better support architectural students in design studios.

REFERENCES

Aliakseyeu, D., J.-B. Martens, et al. (2006). "A computer support tool for the early stages of architectural design." Interacting with Computers 18(4): 528-555.

Bilda, Z. and H. Demirkan (2003). "An insight on designers' sketching activities in traditional versus digital media." Design Studies 24(1): 27-50.

Chen, Z. R. (2007). "How to improve Creativity: Can Designers Improve Their Design Creativity by Using Conventional and Digital media simultaneously?" CAAD Futures 2007, Australia.

Ekelund, W. & Kiviniemi, A. & Kotro, P. & Penttilä, H. (1992). "Arkkitehdin tiedonhallinnan oppikirja." Oulu, Oulun yliopisto Arkkitehtuurin osasto. 165 s.

Gero, J. S. (1990). "Design prototypes: a knowledge representation schema for design." AI Magazine 11(4): 26-36.

Gero, JS, Kan, JWT and Pourmohamadi, M. (2011). "Analysing design protocols: Development of methods and tools," in A Chakrabarti (ed), Research into Design pp. 3-10.

Gross, M., and E. Y. Do. (1996). "Ambiguous Intentions: A Paper-Like Interface for Creative Design." *Proceedings of the ACM UIST Conference*: 183-192. Cambridge: User Interface Software Technology.

Goldschmidt, G. (1994). "On visual design thinking: the vis kids of architecture." Design Studies 15(2): 158-174.

Gu, N., M. J. Kim, et al. (2011). "Technological advancements in synchronous collaboration: The effect of 3D virtual worlds and tangible user interfaces on architectural design." Automation in Construction 20(3): 270-278.

Haapasalo, H. (1997). "Creative Computer Aided Architectural Design." Lisentiate thesis. University of Oulu, Construction economicslaboratory. Oulu. 88 p.

Herbert, D. (1993). *Architectural study drawings.* New York: Van Nostrand Reinhold

Ibrahim, R. and F. Pour Rahimian (2011). "Comparison of CAD and manual sketching tools for teaching architectural design." Automation in Construction 19(8): 978-987.

Kim, M. J. and M. L. Maher (2008). "The impact of tangible user interfaces on spatial cognition during collaborative design." Design Studies 29(3): 222-253.

Kiviniemi, A. & Penttilä, H. (1995)." Rakennus-CAD." Helsinki, Rakennustietosäätiö. 148 s.

Laseau, Paul. (1989). Graphic Thinking for Architects and Designers. 2nd ed. New York: Van Nostrand Reinhold.

McFadzean, J. (1999) "Computational Sketch Analyser (CSA): extending the boundaries of knowledge in CAAD." in Brown, A., Knight, M. and Berridge, P. (eds), Architectural Computing from Turing to 2000 – Proceedings of the 17th Conference on Education in Computer Aided Architectural Design in Europe, The University of Liverpool.

A switching coding scheme for exploring design cognition in mixed media design environments

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ABSTRACT: Mixed media design environments comprise conventional and digital tools, the combination of which is often better than individual tools during the conceptual design phase (Ibrahim and Rahimian, 2010). Both pen-paper sketching and CAD (computer-aided design) modelling are the most popular tools for the contemporary design industry and the education behind it (Romer et al., 2001). When designers switch from sketching to CAD modelling, the shift action of re-thinking the early design improves design creativity (Chen, 2007). In studies into mixed media design environments the focus is often on the early design process, the designers being asked to start by sketching then move to CAD modelling: this method of using mixed media containing one shifting action is called sequential mixed media (SMM). However, there is another way of using mixed media, called alternate mixed media (AMM), in which designers alternate frequently between the two. There is an inadequate number of studies into exploring designers' behaviour in AMM, their shifting actions between tools and the factors triggering the shifting actions. This paper commences with a comprehensive analysis of a wide variety of design tools supporting conceptual design in the early design process; then presents a switching behaviour coding scheme for future study into investigating design cognition between SMM and AMM. The outcome will lead to a more critical understanding of how use of both design tools can be facilitated – more particularly, when and why designers shift from one tool to another tool during the conceptual design phase.

Conference theme: Computer Science
Keywords: Design Cognition, Mixed Media, Design Process, Switching Behaviour Coding Scheme.

INTRODUCTION

Mitchell (1993) strongly recommends a wider application of the different technologies in the design process acknowledging the potential influence between the sketching and digital modelling: an important aspect of this potential is the possibility of using CAD to develop ideas in the early design stage (Mitchell, 1993). Mixed media is believed to enhance the generation of ideas, design communication and decision-making during the conceptual design phase (Ibrahim and Rahimian, 2010). Although there is a variety of research into design tools examining the way in which designers in solo or mixed design environments utilise conventional and digital media, it is not yet clear how the different ways of utilising the tools affects design cognition, specifically during the conceptual design phase, nor what the design processes and strategies of representing the traditional and digital media at higher levels of design cognition.

Several studies explore different types of design media: using a solo design tool during the conceptual design phase (Kavakli and Gero, 2001, Aliakseyeu et al., 2006, Gu et al., 2011, Schweikardt and Gross, 2000); comparing two solo tools in design (Sachse et al., 2001, Won, 2001, Kim and Maher, 2008); comparing solo and mixed design environments (Ibrahim and Pour Rahimian, 2011), e.g. Sachse et al's (2001) study of more than 100 expert engineering designers utilising sketching before and during CAD modelling; found an improvement in the quality of solutions, reduction of time taken and also in the number of processing steps taken in CAD. However, their work did not consider the design activity from a cognitive perspective, specifically the changes of design behaviour in the mixed media environment or the difference between using sketching before and during CAD modelling.

This paper reports on a projects which aims to develop a new coding scheme extending the existing design process and strategies schemes in design cognition, the Function-Behaviour-Structure (FBS) model (Gero, 1990) – adapting it to suit the context of designing in alternate mixed media (AMM) for the purpose of understanding designers' behavioural changes in mixed media environments; and to identify the factors triggering shifts between tools. This paper provides a wide-ranging analysis of a designer's use of design tools, and the rationale for why mixed sketching and CAD modelling design environments require further study. The final section presents protocol analysis, develops a switch behaviour coding scheme and discusses the mixed media theory. The significance of this paper is its contribution to the better understanding of the changes in designers' behaviour in mixed media design environments and the triggering factors involved.

1. RELATED WORKS

Following is the consideration of the current knowledge of the different types of design media, drawing a comparison between the two solo design environments (sketching and CAD), and comparing solo and mixed design environments.

1.1. Types of design environment

The early design process is seen as the cognitive activity of organising ideas to find a solution: it involves both synthesis and analysis of various perspectives of the requirements for finding the main solution. Many designers use visual thinking aided externally; they better understand an idea by sketching it on paper to see if it works. The process by which images are used as fundamental objects for design decision-making is called 'graphical thinking' (Laseau, 1989), 'design drawing' (Lockard, 1982), or simply 'sketching': this iterative method of testing ideas and informing the design phase using images basically directs and aids the designer's decision-making; and is referred to as *'the insightful conversation with images and ideas delivered by the act of drawing'* (Schon and Wiggins, 1992). With Schon's argument we can infer that the reflective conversation is about the designer's *'seeing what is there, drawing in relation to it, seeing what is drawn'*, thus further developing the design; so one of the most important tools that designers have at their disposal in the early design stage is freehand sketching.

In spite of being a premium tool for design there are some constraints in the design activity of sketching. Sketching is a passive tool and relies on initiative from the designer. The fact that sketching isn't digital is the main constraint. All information in industry requires transferring the sketching data into digital format, this being considered a barrier for their concurrent use (Herbert, 1993).

Computer-Aided-Design (CAD) was first developed in the 1960s and has progressed to being an intricate part of architecture (McFadzeam, 1999). Kiviniemi and Penttilä (1995) consider that the major difference between CAD modelling and sketching, the traditionally accepted design medium is the lack of an unambiguous scale. As well, designers use mouse, keyboard and screen design – very different from using pencil and paper: this can initially be a great difficulty because there is no direct physical connection between hand and eye (Ekelund et al., 1992). Sketch design work is done on a sheet at one time, but CAD modelling builds the 3D model through 2D layout, perspective, and other detailed section views (Haapasalo, 1997). The results of design are usually several drawings or one 3D model of the building that is always done in real scale (Penz, 1992). The earliest conceptual design phase for starting with CAD working and the following design phase such as detail design is only need a fine-tuning. The types of design media such as sketching, CAD modelling, and other types of digital tools during the early design process are detailed in Table 1.

Table 1: Types of design environments

Type 1: Sketching (pen and paper)	
Scholars & year	**Research findings**
(Ullman et al., 1990)	The beginning of the action of the sketch is *'to archive the geometric form of the design'*. Sketches provide a way to store the conceptual ideas, so designers can revisit drawings from different point of views.
(Fish and Scrivener, 1990)	Sketching mediate mental translation between spatial cognition and structurally descriptive modes of the visual demonstration.
(Goldschmidt, 1994)	'Seeing-as' and 'seeing-that' modes were developed by observing that architectural students generate unclear and ambiguous sketching that is a significant element of design creativity during the design stages. A designer frequently uses sketches as descriptions of the objects to be designed – called 'interactive imagery'.
(Schon and Wiggins, 1992)	Designing as a conversation with materials via sketching, importantly dependent upon *seeing*. The different types of designers' movements are described as 'seeing–moving–seeing'.
(Scrivener and Clark, 1994)	Sketching provides representations of design solutions that allow for a variety of interpretations and sequential decisions are made that allow for evaluation and interpretation of the design solutions.
(Suwa and Tversky, 1997)	The reinterpretation of the new ways of seeing or shifting focus can contribute to the creative process.
(Purcell and Gero, 1998)	Focus on the role of sketching in design cognition and description of such reinterpretation as *'new ways of seeing of a potential design'*.
(Kavakli et al., 1998)	Drawing behaviour is affected both by task and stage. The sketching behaviour might provide important insights into the nature of the idea development process.
(Verstijnen et al., 1998)	'Combining, Restructuring, Expertise, and Creativity' will separately impact on sketching behaviour. On the basis of their results conclusions are drawn for computerised sketching aids.
(Scrivener et al., 2000)	'Top-down cognitive factors, perception, or a combination of both could trigger switching of drawing behaviour. From the evidence, it is concluded that uncertainty is the primary factor triggering change in drawing structure.'
(Rodgers et al., 2000)	Freehand sketching is prevalent in the conceptual phase of design and the sketching activity has peaks and troughs of both 'lateral and vertical transformations' over time. In this way, sketching can provide insight into the designer's thinking at any particular point in the

	design process.
(Kavakli and Gero, 2001)	Results show that there are differences in the balance of cognitive actions between novice and expert designers.
(van der Lugt, 2005)	The results show that relevant functions of sketching are: firstly, supporting a re-interpretive cycle in the individual thinking process; secondly, enhancing access to earlier ideas.
(Goldschmidt and Tatsa, 2005)	Intensive interlinking among design ideas, design decisions or design moves is the hallmark of good and creative design. Therefore, the answer to the question 'how good are good ideas?' is simply: ideas are as good as suggested by the network of links they create among themselves.
(Menezes and Lawson, 2006)	Evidence from both cognitive psychology and design research supports that the designers, particularly during the conceptual phases of the design process, have a strong interaction with their own sketching. This interaction with sketching seems to be related more to designers than to the action of drawing. The way designers describe things might reflect the way they think, and new thoughts might emerge when they interact with sketching.
Type 2: Digital sketching (Sketch tablet & TUIs)	
Scholars & year	**Research findings**
(Verstijnen et al., 1998)	Electronic sketch tablets, like paper and pencil, support unspecified input idea creation tools. Currently these tablets lack support facilities for restructuring. The efficiency of these tablets for the purpose of idea sketching could be considerably improved.
(Aliakseyeu et al., 2006)	Instead of trying to replace such conventional ways of working, there is attempt to maintain the strengths of these conventional ways of working while at the same time improving them by providing access to new media. The realisation of a tool for early architectural design on an existing augmented reality (AR) system, called the 'Visual Interaction Platform'.
Type 3: 3D virtual worlds and TUIs	
Scholars & year	**Research findings**
(Gu et al., 2011)	The problem is that many design projects occur at the same time but in different locations. They conduct two protocol experiments in 3D virtual worlds: remote design collaboration and collaboration with tangible user interfaces (TUIs), the former to understand the behaviours changing when physically remote but virtually co-located in 3D models. Later study improves designers' cognition when using TUIs combined with augmented reality (AR).
Type 4: Digital clay	
Scholars & year	**Research findings**
(Schweikardt and Gross, 2000)	Digital Clay, a working prototype of a sketch recognition program that interprets gestural and abstracted projection sketching and constructs appropriate 3D digital models.
Type 5: CAD modelling	
Scholars & year	**Research findings**
(van Dijk, 1995)	CAD can fulfil the same role for sketching as word processors do for writing. However, at the moment CAD is still in the 'typewriter' era. If CAD can speed up in terms of UI or hand movements, traditional drawbacks would be eliminated.

1.2. Means for comparing two solo design environments

Table 2 shows that designers using sketching have the better synthesis strategy than using CAD modelling (Bilda and Demirkan, 2003, Stones and Cassidy, 2007). Digital sketching and conventional sketching have no significant differences, because of the features of these two different design tools (Won, 2001). Thus, both sketching and CAD modelling can be used in the early design processes.

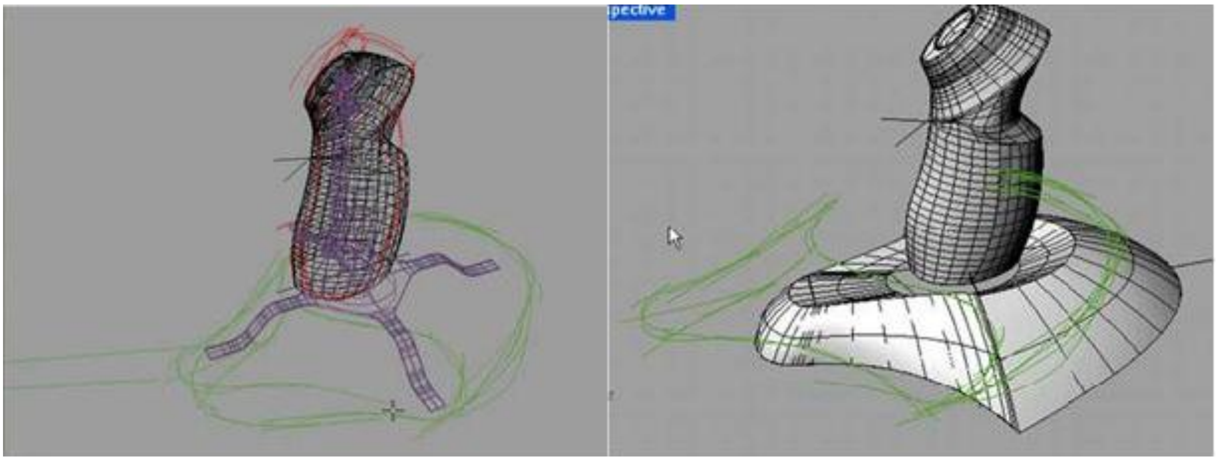
Table 2: Comparing two solo design environments

Type 1: Sketching vs CAD modelling	
Scholars & year	**Research findings**
(Won, 2001)	When designers use conventional media to generate concepts, their cognitive behaviours are simpler than when they use computer tools. The representation of preliminary sketching, the stroke representing the traditional way, is rough, while the CAD way is concrete.
(Bilda and Demirkan, 2003)	Traditional media have advantages over digital media, such as supporting the perception of visual spatial features and relationship of the design, production of alternative solutions and better conception of the design problem.
(Stones and Cassidy, 2007)	Not only is paper-based sketching more effective in producing more solutions than digital work, but also more effective in supporting one particular synthesis strategy.
Type 2: Conventional sketching vs Digital sketching	
Scholars & year	**Research findings**
(Tang et al., 2011)	The design processes using traditional and digital sketching are not yet statistically different.
Type 3: TUIs vs GUIs	
Scholars & year	**Research findings**
(Kim and Maher, 2008)	The main problem of GUIs is that designers cannot design intuitively because they have to use a keyboard and mouse. The results reveal that when designers using TUIs, the inter-

	face changes their spatial cognition and improves problem-finding behaviour.

1.3. Ways of comparing solo and mixed design environments

Table 3 shows comparisons of mixed media to solo media. Interestingly, Huang and Lee's (2004) conduct a comparison experiment – conventional sketching and CAD modelling vs digital sketching and CAD modelling – in which they found that with digital sketching and CAD modelling the designer remained aware of cognitive sketching behaviour while building CAD modelling (Figure 1a). However, digital sketching cannot show all the drawing processes on-screen, and when moving or rotating the 3D model the drawing cannot be matched (Figure 1b).



Source: (Huang and Lee, 2004)

Figure 1a: digital sketching while CAD modelling; Figure 1b: sketching and CAD modelling have a mapping problem

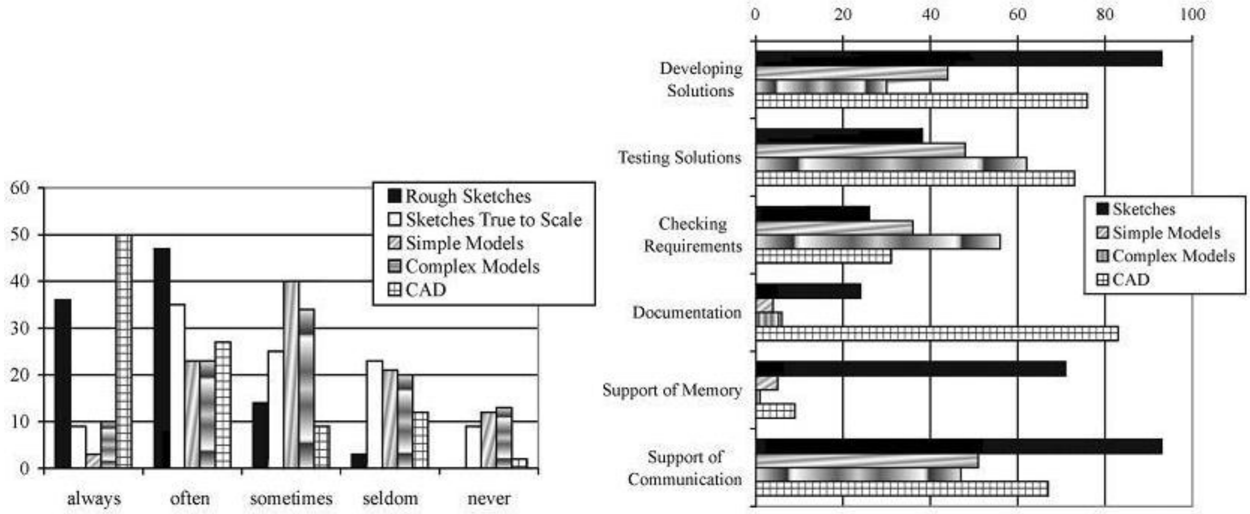
Table 3: Comparing solo and mixed design environments

Type 1: Full sketching vs Mixed media vs Full CAD modelling	
Scholars & year	**Research findings**
(Ibrahim and Pour Rahimian, 2011)	Using mixed media is superior to fully sketching or fully CAD modelling. A VR-based alternative design interface would improve design representation and, hence, enhance cognition and communication among novice designers during the conceptual design phase.
Type 2: Conventional sketching and CAD modelling vs Digital sketching and CAD modelling	
Scholars & year	**Research findings**
(Huang and Lee, 2004)	A new formula for employing digital media that will enable the designer to imagine 2D sketches and computer models simultaneously. In this scenario, the designer can remain aware of cognitive behaviour in sketching while constructing computer models.
Type 3: Haptic CAD & digital sketch vs Physical model & traditional sketch	
Scholars & year	**Research findings**
(Rahimian and Ibrahim, 2011)	Traditional tools (freehand sketch, mock-up) and a haptic device with tangible interface digital tools are compared to understand novice designers' spatial cognition. Main findings show significant improvement for designers' spatial cognition with the haptic device. However, it's expensive, and many designers have no experience of such media.
Type 4: Full sketching vs Mixed media vs Full CAD modelling	
Scholars & year	**Research findings**
(Chen, 2007)	Studies graphic design by using conventional and digital media simultaneously and finds that design creativity occurs when shifting tools.

1.4. Why study mixed sketching and CAD modelling design environments?

Romer et al. (2001) through the use of a survey of 106 designers enquired 'how often do you use …?' and 'what do you use … for?' in terms of sketches, models and CAD. Figure 2a shows that rough sketching is the most popular external tool; but there is no significant difference between rough sketching and CAD overall. Figure 2b shows that sketches are used significantly for solution development, supporting the memory and communication; while CAD is used largely for solution development, testing solutions, documentation and supporting communication. These are the most popular and functional external tools, and the main focus of this research project.

Many architects still prefer to use pen and paper or scale models in the early design stage (Gross and Do, 1996), though in the Gross and Do report that it offers the required flexibility, speed and intuitive interaction. This way of working, however, creates an interruption in the design process flow; since the designers have to transfer their design works to CAD modelling specifications after the early design stage. In order to reduce the time spent on this transition, more and more architects are using programs like AutoCAD and ArchiCAD in all stages (Lawson, 1999). In interior design, the ideation process is based on the technical plan of the space, followed by freehand perspective views or accurate perspective rendering (Dorta and Perez, 2006). On one hand, the problems of freehand sketching appear to be understanding complex 3D shapes, unconscious proportion errors, disregard for human scale, and the observer's angle of vision (Landsdown, 1994); while on the other hand, typical computer representation can affect the conceptual design process – the interface, the accuracy, the lack of abstraction and absence of ambiguity. Most of the solutions proposed to integrate the sketch into the digital design process seem to take a particular path to imitating or simulating the real sketch (Jatupoj, 2005).



Source: (Romer et al., 2001)

Figure 2a: Frequency of use of external representations (in %); Figure 2b: Purposes of using external representations (in %)

2. COGNITION IN MIXED MEDIA DESIGN ENVIRONMENT: AN APPROACH

Table 4 provides an overview of research methods previously used on designers' behaviour whilst utilising external aids such as sketching or CAD. Protocol analysis has been employed in an endeavour to better understand the difference between novice and expert designers (Kavakli and Gero, 2001), the study of design strategies (Stones and Cassidy, 2007), and the comparison of traditional and digital sketching (Tang et al., 2011). Researchers have combined two methods, protocol analysis and the analysis of variance (ANOVA), to understand the design process as well as evaluate design outcomes (Sachse et al., 2001, Ibrahim and Pour Rahimain, 2011); these would all support the application of Protocol Analysis as an appropriate method for better understanding the design activity in a mixed media situation.

Table 4: Types of research methods

Method 1: Protocol analysis	
Scholars & year	**Procedures**
(Kavakli and Gero, 2001)	**Subjects:** novice and expert designers **Coding scheme:** adapted from Suwa and Tversky (1997) **Design media:** sketching
(Stones and Cassidy, 2007)	**Subjects:** student designers **Coding scheme:** develop six types of synthesis strategies: unconnected, touching, overlapping, enclosed, joined, and contributing **Design media:** digital and paper-based tools
(Tang et al., 2011)	**Subjects:** novice designers **Coding scheme:** adapted from Gero's FBS model **Design media:** traditional and digital sketching
Method 2: Combined protocol analysis with ANOVA	
Scholars & year	**Procedures**
(Sachse et al., 2001)	**Subjects:** novice designers **Evaluation criteria:** six types of physical operation steps **Design media:** CAD modelling and CAD modelling with sketching
(Ibrahim and Pour Rahimian, 2011)	**Subjects:** novice designers **Coding scheme:** adapted from M.Schtze et al. (2003) **Evaluation criteria:** score 1 to 5 for assessing the quality of the solution **Design media:** sketching, CAD modelling, and mixed media
Method 3: Combined protocol analysis with Linkograph	
Scholars & year	**Procedures**
(Goldschmidt, 1990)	Every pair of moves in a given sequence of moves is checked for the existence of links, which are then notated in a graph called Linkograph.
Method 4: Combined questionnaire survey with SPSS	
Scholars & year	**Procedures**
(Römer et al., 2001)	200 questionnaires posted to designers, 106 completed questionnaires sent back. Questionnaire data analysed by employing descriptive statistics.

2.1. Protocol analysis

Protocol analysis has been accepted as a prevailing approach for elucidating the design process in the design community; it is an experimental technique to clarify understanding of how designers think. This is a methodology which often uses the *"think aloud"* approach to documenting and analysing a designer's decision-making processes; it is an ethnographic approach to capturing and analysing thought processes as they inform the physical actions of the designer.

Many scholars separate the protocol technique into two categories – retrospective and concurrent protocols. Concurrent protocols focus on a process-oriented aspect of designing based on the information-processing view; while retrospective protocols focus on a content-oriented aspect of designing based on the reflection-in-action view (Schon, 1983). Much protocol research has asked subjects to think aloud and sketch simultaneously. Ericsson and Simon (1993) initially study protocol analysis as a valid technique for using utterances to explore the human cognitive activities. Retrospective protocols utilise the retrospective report method: a participant is asked to report their thinking after the task. Therefore, the protocol method is suitable for all designers in the experiment.

To achieve the aims and objectives we adopt the following two types of protocol analysis: think-aloud and retrospective methods. The think-aloud method asks participants to verbalise while they carry out problem-solving activities (Ericsson and Simon, 1993); it can retrieve sequential information and design strategies during designing, based on short-term memory. The AMM design environment could make it difficult to explore the reasons for participants' switching between the two design tools in the early, middle and later design processes of the conceptual design phase: retrospective protocol is an appropriate methodology to investigate the notion of reflection-in-action (Schon, 1983) and perceptual aspects such as triggering factors relating to designers. The method has been conducted with video aids to enhance retrieval from long-term memory (Suwa and Tversky, 1997). The two kinds of protocols will assist in better understanding the impact of AMM.

2.2. Gero and Suwa's coding scheme

Designing is a purposeful action that includes thinking, evaluation and decision making. External tools such as sketching and CAD modelling have the potential to enhance complex problem analysis, solution generation, evaluation and external storage (Romer et al., 2001, Sachse et al., 1999). Gero (1990) devises a design prototype model called Function-Behaviour-Structure (FBS) to retrieve design processes and information. The FBS model has the categories- requirements, function, expected behaviour, structural behaviour, structure, and description. Table 5 defines these:

Table 5: Categories of Gero's FBS coding scheme

Categories	Description	Examples
Requirements (R)	The final goal of designing is to transform a set of requirements (R).	Yes, I'm an eight.
Function(F)	The function (F) of an object is defined as its intended purpose or teleology.	I do lots of walking, so
Expected Behaviour (Be)	The behaviour of the design is expected (Be).	But, you know, if you have something that goes with every thing you wear.
Structural Behaviour (Bs)	The behaviour of the design is derived from its structure (Bs).	I like ... the style of the shoe.
Structure (S)	The structure (S) describes the components and their relations in the design.	Do I select all those material? Or...
Description (D)	Functions into a set of descriptions (D).	[Description] selecting size.

Source: (Gero et al., 2011)

The main purpose of coding schemes, especially when analysing AMM, is to classify protocol data retrieved from the three design environments. Our hypotheses are that

- AMM involves many switching actions which may change the design process, and that
- these changes affect design strategies which facilitate problem-solving.

With regard to the design process and strategies, the FBS coding scheme will be adopted (Gero, 1990), with its six categories and associated eight design strategies of formulation, synthesis, analysis, evaluation, documentation, reformulation 1, 2, and 3 (Table 6).

Table 6: Categories of FBS design strategies

Design strategies	Description
Formulation	Formulation which transforms functions into a set of expected behaviours (F>Be).
Synthesis	Synthesis, where a structure is proposed to fulfil the expected behaviours (Be>S).
Analysis	An analysis of the structure produces derived behaviour (S>Bs).
Evaluation	An evaluation process acts between the expected behaviour and the behaviour derived from structure (Be>Bs or Bs>Be).
Documentation	Documentation, which produces the design or partial design description (S>D).
Reformulation 1	Reformulation of structure (S>S).

Reformulation 2	Reformulation of expected behaviour (S>Be).
Reformulation 3	Reformulation of function (S>F).

Source: (Gero et al., 2011)

For the switching behaviour aspect, participants will be asked to look in retrospect on each shifting behaviour, so we will be adopting Suwa et al.'s (1998) four-level coding scheme of physical, perceptual, functional and conceptual (Table 7). These two types of coding scheme have been widely used for exploration into design cognition research.

Table 7: Categories of Suwa's coding scheme

Four Categories	Description
Physical	Refers to actions that have direct relevance to physical depictions.
Perceptual	Refers to actions of attending to visuospatial features.
Functional	Refers to actions of conceiving of non-visual information which depicted elements and their visuospatial features are able to carry.
Conceptual	Refers to cognitive actions that are not directly suggested by physical depictions or visuospatial features of elements.

Source: (Suwa et al., 1998)

CONCLUSION AND FUTURE WORK

Thus far the paper has provided a rationale and a methodology for the need to better understand the design activity and the cognition which underpins it in an AMM design environment. The next phase of the project is to conduct a pilot study for the purpose of gathering information regarding design cognition for analysis of designers' behaviour while they are working on mixed media design environments (SMM and AMM). The Pilot Study has two functions: (1). to explore whether the experimental design is achieves the purposes of the project and satisfying the research requirements; (2). to test whether meaningful patterns emerge through the application of the adopted the coding schemes. The pilot will involve two architectural design students who are competent with both sketching and CAD modelling. Two design tasks with similar complexities are a two-floor design office and a two-floor dream apartment, and they will be used randomly for the participants. There are five steps to analyse protocols of the pilot study: (1). Transcribing the protocols. (2). Segmenting the protocols. (3). Coding the protocols. (4). Generating linkographs. (5). Interpreting the results of these measures. This paper identifies a gap in our understanding of the impact of mixed media design environments that integrate digital technologies – i.e., CAD modelling – with traditional modes of design such as sketching. The paper precedes the research instigation, but provides an appreciation of need and an approach to gain a better understanding of the application of tradition and current technology in support of the design process.

REFERENCES

Aliakseyeu, D. and Martens, J. B. (2006) A computer support tool for the early stages of architectural design. *Interacting with Computers,* 18(4), 528-555

Bilda, Z. and Demirkan, H. (2003) An insight on designers' sketching activities in traditional versus digital media. *Design Studies*, 24(1), 27-50

Chen, Z. R. (2007) How to improve Creativity: Can Designers Improve Their Design Creativity by Using Conventional and Digital media simultaneously? *CAAD Futures 2007,* Australia

Dorta, T. and Perez, E. (2006) Immersive Drafted Virtual Reality a new approach for ideation within virtual reality, Synthetic Landscapes, *Proceedings of the 25th Annual Conference of the Association for Computer-Aided Design in Architecture*, pp. 304-316

Ekelund, W., Kiviniemi, A., Kotro, P. and Penttilä, H. (1992) Arkkitehdin tiedonhallinnan oppikirja. *Oulun yliopisto Arkkitehtuurin osasto*, Oulu

Ericsson, K. A. and Simon, H. A. (1993) *Protocol Analysis: Verbal Reports as Data.* MIT Press, Cambridge

Fish, J. and Scrivener, S. (1990) Amplifying the mind's eye: sketching and visual cognition. *Leonardo,* Vol 23, No1, pp 117-126

Gero, J. S. (1990) Design prototypes: a knowledge representation schema for design. *AI Magazine*, 11(4), 26-36

Gero, J. S., Kan, J.W.T. and Pourmohamadi, M. (2011) Analysing design protocols: Development of methods and tools. *Research into Design,* pp. 3-10

Gross, M. and Do, E. Y. (1996) Ambiguous Intentions: A Paper-Like Interface for Creative Design. *Proceedings of the ACM UIST Conference*, 183-192

Goldschmidt, G. (1994) On visual design thinking: the vis kids of architecture. *Design Studies,* 15(2), 158-174

Goldschmidt, G. and Tatsa, D. (2005) How good are good ideas? Correlates of design creativity. *Design Studies*, 26(6), 593-611

Gu, N., Kim, M. J. and Maher, M. L. (2011) Technological advancements in synchronous collaboration: The effect of 3D virtual worlds and tangible user interfaces on architectural design. *Automation in Construction,* 20(3), 270-278

Haapasalo, H. (1997) *Creative Computer Aided Architectural Design.* University of Oulu, Lisentiate thesis

Herbert, D. (1993) *Architectural study drawings.* Van Nostrand Reinhold, New York

Huang, Y. S. and Lee, J. (2004) The New Combination of Digital Sketching and Modeling Process in Idea-Developing Stage. *CAADRIA 2004,* Seoul Korea, pp. 545-556

Ibrahim, R. and Rahimian, F. P. (2011) Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction*, 19(8), 978-987

Jatupoj, P. (2005) Sketch board: the simple 3D modelling from architectural sketch recognition. *Proceedings of the CAADRIA'05 Conference*, 3-22

Kavakli, M. and Gero, J. S. (2001) Sketching as mental imagery processing. *Design Studies,* 22(4), 347-364

Kavakli, M., Scrivener, S. A. R. and Ball, L. J. (1998) Structure in idea sketching behaviour. *Design Studies,* 19(4), 485-517

Kim, M. J. and Maher, M. L. (2008) The impact of tangible user interfaces on spatial cognition during collaborative design. *Design Studies,* 29(3), 222-253

Kiviniemi, A. and Penttilä, H. (1995) *Rakennus-CAD.* Helsinki, 148

Lansdown, J. (1994) *Visualizing Design Ideas: In Interacting with Virtual Environments,* eds. L. MacDonald and J. Vince, 61 - 77. Toronto, Wiley

Laseau, P. (1989) *Graphic thinking for architects and designers.* Von Nostrand-Reinhold, New York

Lockard, W. K. (1982) *Design Drawing*. Tucson: Pepper Publishing

McFadzean, J. (1999) Computational Sketch Analyser (CSA): extending the boundaries of knowledge in CAAD. In Brown, A., Knight, M. and Berridge, P. (eds), *Architectural Computing from Turing to 2000 – Proceedings of the 17th Conference on Education in Computer Aided Architectural Design in Europe,* The University of Liverpool, Liverpool, pp. 503-510

Menezes, A. and Lawson, B. (2006) How designers perceive sketches. *Design Studies*, 27(5), 571-585

Mitchell, W. J. (1993) A computational view of design creativity. In Gero, J. S.and Maher, M. L. (Eds.), *Modelling creativity and knowledge-based creative design*: 25-42. Hillsdale, NJ, Erlbaum Press

Purcell, A. T. and Gero, J. S. (1998) Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology. *Design Studies,* 19(4), 389-430

Penz, F. (1992) Computers and Architecture: Tools for Design. London, United Kingdom, *Longman Group.* pp.152

Rahimian, F. P. and Ibrahim, R. (2011) Impacts of VR 3D sketching on novice designers' spatial cognition in collaborative conceptual architectural design. *Design Studies*, 32(3), 255-291

Rodgers, P. A., Green, G. and McGown, A. (2000) Using concept sketches to track design progress. *Design Studies,* 21(5), 451-464

Römer, A., Pache, M., Weißhahn, G., Lindemann, U. and Hacker, W. (2001) Effort-saving product representations in design-results of a questionnaire survey. *Design Studies*, 22(6), 473-491

Sachse, P., Leinert, S. and Hacker, W. (2001) Designing with computer and sketches. *Swiss Journal of Psychology*, 60(2), 65-72

Schon, D. A. (1983) *The Reflective Practitioner*, Harper Collins, New York

Schon, D. A. and Wiggins, G. (1992) Kinds of seeing and their functions in designing. *Design Studies*, 13(2), 135-156

Schweikardt, E. and Gross, M. D. (2000) Digital clay: deriving digital models from freehand sketches. *Automation in Construction,* 9(1), 107-115

Scrivener, S. A. R. and Clark, S. M. (1994) Sketching in collaborative design in L MacDonald and J Vince(eds) *Interacting with virtual environments, Wiley,* Chichester, UK

Scrivener, S. A. R., Ball, L. J. and Tseng, W. (2000) Uncertainty and sketching behaviour. *Design Studies,* 21(5), 465-481

Stones, C. and Cassidy, T. (2007) Comparing synthesis strategies of novice graphic designers using digital and traditional design tools. *Design Studies,* 28(1), 59-72

Suwa, M., Purcell, T. and Gero, J. (1998) Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies,* 19, 455-483

Suwa, M. and Tversky, B. (1997) What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies*, 18(4), 385-403

Tang, H. H., Lee, Y. Y. and Gero, J. S. (2011) Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function-behaviour-structure coding scheme. *Design Studies,* 32(1), 1-29

Ullman, D. G., Wood, S. and Craig, D. (1990) The importance of drawing in the mechanical design process. *Computers & Graphics,* 14(2), 263-274

van der Lugt, R. (2005) How sketching can affect the idea generation process in design group meetings. *Design Studies,* 26(2), 101-122

van Dijk, C. G. C. (1995) New insights in computer-aided conceptual design. *Design Studies*, 16(1), 62-80

Verstijnen, I. M., Leeuwen, C. V., Goldschmidt, G., Hamel, R. and Hennessey, J. M. (1998) Creative discovery in imagery and perception: Combining is relatively easy, restructuring takes a sketch. *Acta Psychologica,* 99(2), 177-200

Won, P. H. (2001) The comparison between visual thinking using computer and conventional media in the concept generation stages of design. *Automation in Construction,* 10(3), 319-325

M. A. Schnabel (ed.), *Cutting Edge: 47th International Conference of the Architectural Science Association,* pp. 123–132.

USING FBS ONTOLOGY TO ANALYSE AND COMPARE DESIGNERS' REASONING PROCESSES IN SMM AND AMM DESIGN ENVIRONMENTS

A pilot study with architectural designers

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Abstract. This paper presents the results of a pilot protocol study of the design behaviour differences of designers. The aim of the study reported in this paper is to understand the similarities and differences in designers' behaviour using Sequential Mixed Media (SMM) and Alternative Mixed Media (AMM), and how switching between media may impact the design process. Two designers with at least one-year's professional design experience and with a Bachelor of Design degree, and are competent at both sketching and CAD modelling, participated in the pilot study voluntarily. Video recordings of designers working on different pilot projects were coded utilising Function-Behaviour-Structure (FBS) ontology and interviews of switching were categorised into three types. Preliminary results indicate that switches between sketching and CAD modelling may influence how designers identify problems and develop solutions. In particular, some codes of structure change to documentation when switching from sketching to CAD modelling. These switches are able to integrate both design tools into one design medium.

Keywords. Design behaviour; FBS ontology; mixed media; protocol analysis.

1. Introduction

Current research has shifted from analysing individual design media to analysing the impact mixed media on designers' behaviour during the early phases of design. In empirical studies conducted by Chen (2007) and Ibrahim and Rahimian (2011), designers were asked to initially use traditional sketching before shifting to CAD modelling. This use of mixed media, in which one shift between media occurs, is defined as Sequential Mixed Media (SMM). Researchers (Do 2005; Sachse et al., 2001) have found, however, that designers prefer to move freely between media, alternating between sketching and CAD modelling as it suits them (like Do's (2005) concept of "the right tool at the right time"). This method is termed Alternative Mixed Media (AMM) and is popular among designers and design students.

This paper presents the results of a pilot study of the different design behaviour of architectural designers when using SMM and AMM. Most of the understanding have about designers' behaviour in mixed media environments is based on studies of SMM. Few studies have used AMM to explore the switches between design tools and the factors that trigger these switches (author). This paper reports on a pilot study of SMM and AMM design sessions using protocol analysis. When switches in AMM design sessions were observed, the designers were interviewed and asked for their reasons for switching. Interviews were conducted after design tasks had been completed. The designers' behaviour using SMM and AMM were compared and the impacts of the switches on AMM design process were explored.

In the remainder of this paper, the concept of mixed media design studies, protocol studies, and the framework for applying FBS ontology in mixed media are introduced. The pilot study is then presented. The final part of the paper discusses the preliminary results and the impact of switches on the design process.

2. Protocol Studies

To better understand the differences of designers' behaviour in the design process as described above, protocol analysis, which involves a "think aloud" approach to document and analyse a designer's decision-making processes, will be utilised. Protocol analysis is an ethnographic approach to capturing and analysing thought processes in order to determine the ways in which these thought processes inform the physical actions of the designer. The designers' behaviour and spoken thought processes are then encoded against a predetermined coding scheme. Protocol analysis will assist in better understanding the impact on designers' behaviour during the design process.

Gero's Function-Behaviour-Structure (FBS) framework was developed in 1990 and has evolved over the last two decades. Many protocol design studies have adopted the FBS model to describe design processes and tasks (Gero and Kannengiesser, 2004). Some researchers argue that the definition of function has not been stable over the years and that the FBS model is both descriptive of actual designing and prescriptive of improved designing (Tang et al., 2011). Thus, the definition of FBS has been revised to encompass this.

The FBS model is defined as a process-oriented design theory in which designing is understood as a sequence of distinguishable stages.

FBS ontology (Figure 1) situates designing in terms of three basic classes of variables: function, behaviour, and structure. In this view, the goal of designing is to transform a set of functions into a set of design descriptions (D). The function (F) of a designed object is defined as its purposes or teleology. The behaviour (B) of that object is how it achieves its functions and is either derived (Bs) or expected (Be) from the structure. The structure (S) comprises the elements of an object and their relationships. A design description is never transformed directly from the function but undergoes a series of processes among the FBS variables. These processes include: a formulation (F > Be) which transforms functions into a set of expected behaviours; a synthesis (Be > S), wherein a structure is proposed that is likely to exhibit the expected behaviour; an analysis (S > Bs) of the structure produces its derived behaviour; an evaluation process (Bs - Be) acts between the expected behaviour and the behaviour derived from structure; and documentation (S > D), which produces the design description [6,10,11]. Depending on the structure there are three types of reformulation, where new variables are introduced: reformulation of structure (S > S), reformulation of expected behaviour (S > Be), and reformulation of function (S > F). Reformulation of function is relatively rare, as it changes or redefines the design problem.

Finally, the primary advantage of FBS model is that it clearly shows the relationships between the eight transformation processes and the three basic classes of variables, therefore, this model will be applied in the study to identify behavioural patterns in SMM, and AMM design sessions.

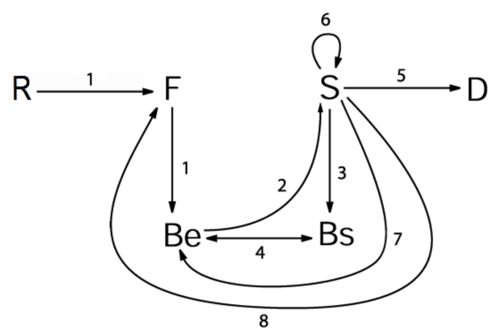


Figure 1. FBS ontology (taken from Gero, 1990).

2.1. DEVELOPMENT MIXED MEDIA CODING STRUCTURE

This paper studied designers' behaviour when using a mixed media design environment unlike other research (Bilda and Gero, 2006; Suwa et al., 1997;

1998; 2000) which studied designers' behaviour when using single design environments. Both sketching and CAD modelling facilitate design processes as external aids. A coding scheme structure has to distinguish the designers' behaviour in both design environments when using mixed media (Figure 2). Based on FBS ontology, both sketching and CAD modelling design environments consist of six design issues (R, F, Be, Bs, S, and D) so that different distributions of the design issues can be compared when using SMM and AMM.

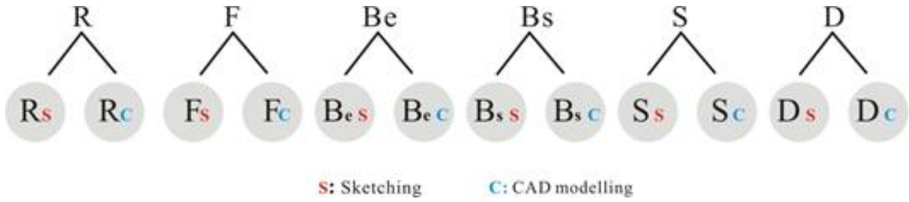


Figure 2. Structure of FBS ontology in mixed media design environment.

3. Experiment Design

Protocol analysis can be used for a single participant, or a team of participants. However, it is important to minimise the participants' influences in order to ensure the reliability of the results. Two architectural designers were recruited as participants in the pilot study, initially from those whose responses indicate they could best satisfy the criteria. In order to be included in this pilot study, the designers must have: 1. a tertiary degree in architecture with a minimum of one-year of professional architectural practice experience; 2. design degrees that have been obtained within the last three years so that the professional architectural practice experience is similar; 3. competence in both sketching and CAD modelling (e.g. ArchiCAD); and 4. competence in practising and communicating design in the English language. Architectural designers often design buildings such as houses and office buildings, so this study provides an existing building model, including the 2D layout and CAD model. Participants were then asked to use this model to randomly design a building for different purposes: office, dream apartment, and art gallery design.

4. Pilot Results

4.1. CATEGORISATION INTERVIEW OF DESIGN SWITCHES

The participants' interviews for their switches after AMM session were conducted. The interviews with participants pointed out to a single conclusion that they would not find it as easy to design if they were not allowed to switch. The common view was that by switching between sketching and CAD modelling they were able to complete the design task smoothly. The process was likened to tracing their idea from one paper to another. Table 1 shows examples of design switches including "eye" and "eye with hand" from sketching to CAD modelling or CAD modelling to sketching.

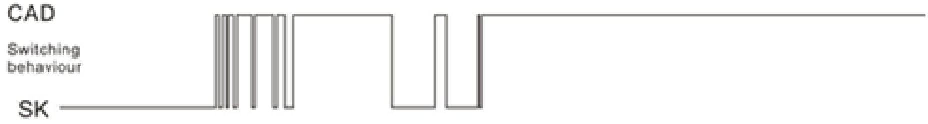
Table 1. Examples of design switches.

Design switch	Types	Participant A	Participant B
Sketching→ CAD modelling	Eye		
	Eye and hand		
CAD modelling →Sketching	Eye		
	Eye and hand		

Figure 3 demonstrated that design switches between sketching and CAD modelling are essential. Categorising the information we obtained in the interviews with our participants we summarised what design switches do for them:

- The first type of the design switch, from sketching to CAD modelling (S→C), changes a design issue of FBS ontology from structure (S) to documentation (D): "I was trying the hand-sketched design in the CAD environment so as to better understand its function in terms of scale, section and elevation" and "moved it onto CAD".
- The second type of the design switch, back and forth between sketching/ CAD modeling and design brief (S/C⇆R) within seconds, evaluates the similarity and difference between their sketches/CAD models and design briefs which will be coded requirements (R): "I was switching back and forth so I can check that I have satisfied the requirements of the set brief".

Participant A:



Participant B:

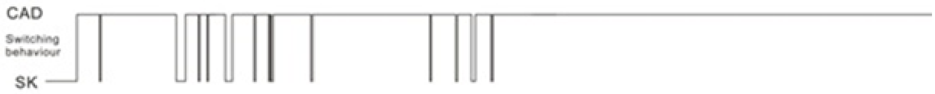


Figure 3. Participant A and B in AMM design session.

4.2. COMPARSION FBS DESIGN ISSUE DISTRIBUTION BETWEEN SMM AND AMM

In this section, we report the general results of protocol coding by applying the Delphi method (Gero and McNeill, 1998). A high level of agreement was achieved between arbitrated protocols and two rounds of coding which contains an interval of two weeks. The coding consistency shown in Table 2 demonstrated the coding of protocol data was reliable. Then we report the comparisons of design issues distribution between SMM and AMM.

Table 2. Summary of segmentation and coding results

Participants	Design sessions	Coding 1 vs. Arbitrated (%)	Coding 2 vs. Arbitrated (%)
Participant A	SMM	76.5	84.8
	AMM	74.1	86.3
Participant B	SMM	77.2	82.7
	AMM	72.8	85.4

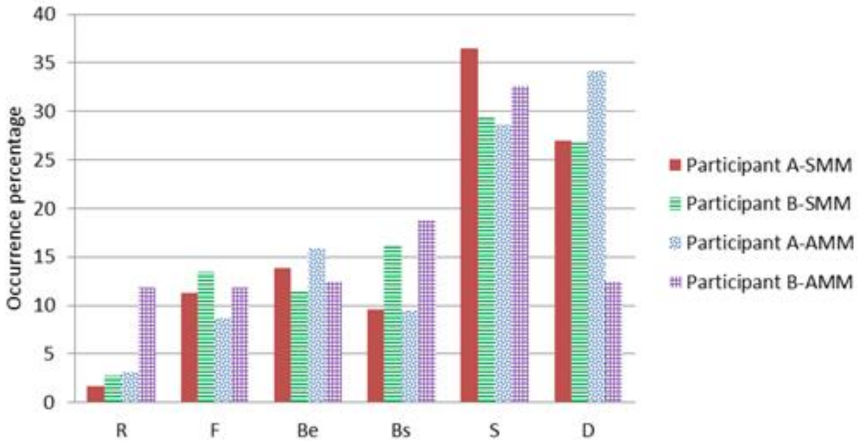


Figure 4. Design issue distributions of participant A and B in SMM and AMM.

Since the design sessions and participants varied, we normalised the frequency distribution of design issues by converting to occurrence percentages, as shown in Figure 4. Participant A and participant B produced qualitatively similar distributions in design issues in SMM and AMM. The six design issues of their cognitive activities can be divided into three groups in the following order: structure (S) and documentation (D) > actual behaviour (Bs), expected behaviour (Be) and function (F) > requirement (R). In AMM design sessions, documentation (D) of participant A was significantly higher than that of participant B (34.1% > 12.5%). In contrast, requirement (R) of participant B was significantly higher than that of participant A (11.8% > 3.2%). These changes demonstrate that designers' switches may impact on their design processes when using AMM.

In the following data analysis, we preset the above two design issue distributions in sketching and CAD modelling for SMM and AMM design sessions (Figure 5). A comparison of the two participants' results shows that the total distribution of documentation (D) issue in SMM is similar; the percentage of using sketching and CAD modelling is similar. On the other hand, participant A produced a higher percentage on documentation (D) in terms of total, sketching and CAD modelling distributions than participant B's. There are a number of reasons why participant A's switches change the design issue from structure (S) to documentation (D): "Transferring the sketch plan to the CAD environment" and "Then moved it onto CAD", as referred to the first type of design switch (S→C) in the context of the paper. Figure 6 shows how participant A facilitated the design process on documentation (D) issues by switching between sketching and CAD modelling.

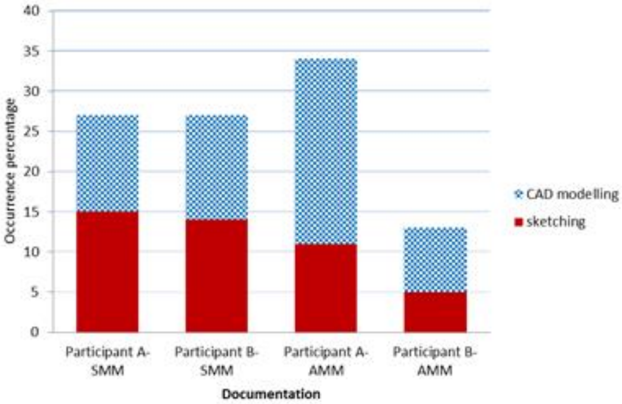


Figure 5. Documentation distributions of participant A and B in sketching and CAD.

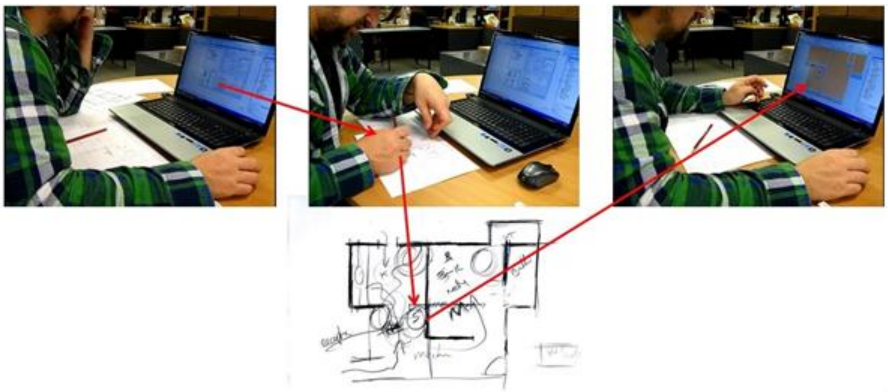


Figure 6. Examples of participant A's design switches.

Figure 7 shows that participant B produces the highest percentage on requirement (R) because he regularly switches between sketching/ CAD modelling and the design brief. The reasons given are: "I moved from sketching to the CAD environment because I wanted to start designing in a virtual setting to understand the spatial and scale requirements of the brief. I noted that as the 3D model is readily available, I can begin to make immediate changes to form the new design proposal"; "I noted that I was cross-checking the requirements of the brief so I can keep on task with my current design intentions" and "In the final stages of completion, I noted that I was switching back and forth so I can check that I have satisfied the requirements of the set brief", as referred to in the second type of design switch (S/C⇆R) in the context of the paper. In addition, this type of design switch refers to the previous protocol studies such as "situative invention (S-invention)" and "co-evolution". According to Suwa et al. (2000), S-invention refers to designer activities that extend beyond the initial definitions of the problem-space, helping designers to form new goals for the solution-space to address significant parts of the design problem. Cross and Dorst (1999) posited the modelling of the design creativity as a co-evolution for both problem and solution spaces.

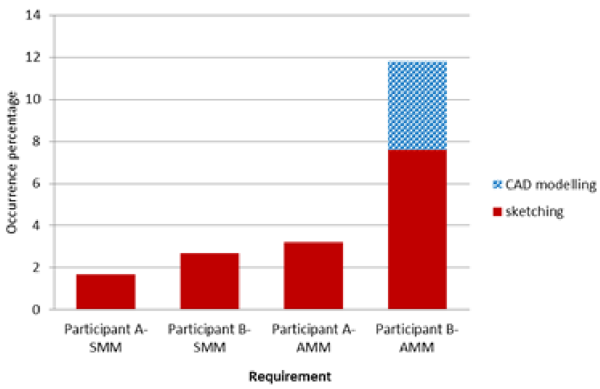


Figure 7. Requirement distributions of participant A and B in sketching and CAD.

5. Discussion and Conclusion

The main question addressed by this study was whether designers' switches between sketching and CAD modelling can influence design processes. We hypothesised that designers' switches are effective in influencing design processes. Several lines of evidence support the hypothesis. First, we showed that the designers switched many times between sketching and CAD modelling during AMM design processes. Second, a design issue will change from structure to documentation when designers switch from sketching to CAD modelling. A possible mechanism by which designers' switches influence the design processes is Do's concept of "the right tool at the right time" (Do, 2005). A few published studies (Chen, 2007; Ibrahim and Rahimian, 2011) in design behaviour have found mixed media is the most effective external representation tool because it generates higher quality solutions than CAD modelling on its own. However, most of these studies were asked to initially use sketching before shifting to CAD modelling. Interestingly, we observed that the designers spent more time on CAD modelling than sketching during designing. One advantage of our study is the AMM experimental set-up, which is close to the real design circumstances. In conclusion, this study demonstrates that the designers' switches are effective in influencing design processes because the switches integrate both sketching and CAD modelling as one design medium.

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References

Bilda, Z. and Gero, J. S.: 2006, To sketch or not to sketch? That is the question. *Design Studies*, **27**(5), 587–613.

Chen, Z. R.: 2007, How to improve creativity: can designers improve their design creativity by using conventional and digital media simultaneously? *CAAD Futures 2007, Australia.*

Cross, N. and Dorst, K.: 1999, Co-evolution of Problem and Solution Space in Creative Design, in J. S. Gero and M.L. Maher (eds.) *Computational Models of Creative Design IV*, Key Centre of Design Computing, University of Sydney, 243–262.

Ellen Yi-Luen Do: 2005, Design Sketches and Sketch Design Tools, *in KBS - Knowledge Based Systems* (18) 383–405

Gero, J. S. and Kannengiesser, U.: 2004, The situated Function-Behaviour-Structure framework, *Design Studies*, 25(4) 373–391.

Gero, J. S., and McNeill, T.: 1998, An approach to the analysis of design protocols. *Design Studies*, 19(1), 21–61.

Ibrahim, R. and Rahimian, F. P.: 2011, Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction*, 19(8), 978–987.

Sachse, P., Leinert, S. and Hacker, W.: 2001, Designing with computer and sketches, *Swiss Journal of Psychology*, 60(2), 65–72.

Suwa, M., Purcell, T. and Gero, J.: 1998, Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies,* 19, 455–483.

Suwa, M. and Tversky, B.: 1997, What do architects and students perceive in their design sketches? A protocol analysis, *Design Studies,* 18(4), 385–403.

Suwa, M., Gero, J. and Purcell, T.: 2000, Unexpected discoveries of design requirements: important vehicles for a design process, *Design Studies*, 21(4), 539–567

Tang, H. H., Lee, Y. Y. and Gero, J. S.: 2011, Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function-behaviour-structure coding scheme. *Design Studies,* **32**(1), 1–29.

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UNDERSTANDING CREATIVE DESIGN PROCESSES BY INTEGRATING SKETCHING AND CAD MODELLING DESIGN ENVIRONMENTS
A Preliminary Protocol Result from Architectural Designers

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Abstract
This paper presents the results of a preliminary protocol study of the cognitive behaviour of architectural designers during the design process. The aim is to better understand the similarities and differences in cognitive behaviour using Sequential Mixed Media (SMM) and Alternative Mixed Media (AMM) approaches, and how switching between media may impact on design processes. Two participants with at least one-year's professional design experience and a Bachelor of Design degree, and competence in both sketching and computer-aid design (CAD) modelling participated in the study. Video recordings of participants working on different projects were coded using the Function-Behaviour-Structure (FBS) coding scheme. Participants were also interviewed and their explanations about their switching behaviours were categorised into three types: S→C, S/C⇆R and C→S. Preliminary results indicate that switching between media may influence how designers identify problems and develop solutions. In particular, two design issues were identified. These relate to the FBS coding scheme, where structure (S) and behaviour derived from structure (Bs), change to documentation (D) after switching from sketching to CAD modelling (S→C). These switches make it possible for designers to integrate both approaches into one design medium and facilitate their design processes in AMM design environments.

Keywords: *Creative design process, sketching, CAD modelling, cognitive behaviour, mixed media design environments.*

INTRODUCTION

Due to the increased globalisation of architecture, engineering and construction (AEC) projects, current research has shifted from individual design environments to the integration of different design environments to achieve better outcomes (Gouldinget al., 2014). According to a survey of 106 expert designers conducted by Romer et al. (2001), the two most frequently used design media in the design industry and design schools are sketching and computer-aided design (CAD) modelling. The integration of sketching and CAD modelling form mixed media design environments. In empirical studies conducted by Chen (2007) and Ibrahim and Rahimian (2011), designers were asked to initially use traditional sketching before shifting to CAD modelling. For the purpose of this research, this use of mixed media, in which one shift between media occurs with no backtracking allowed, is defined as Sequential Mixed Media (SMM). However, researchers (Do, 2005; Sachse et al., 2001) found that designers prefer to move freely between media, alternating at will between sketching and CAD modelling. This method is termed Alternative Mixed Media (AMM) and is a process frequently used by designers. Most of the understanding about cognitive behaviour in mixed media design environments is based on studies in SMM environments. However, there is little empirical evidence that supports a comprehensive understanding of cognitive behaviour in AMM design environments. Questions about the differences between SMM and AMM and whether switching between media impacts on the design process remain unanswered and are therefore important to explore.

To address these questions, a protocol study was conducted in which two professional architectural designers were asked to perform an architectural design task in SMM and AMM design environments. Protocol analysis and the Function-Behaviour-Structure (FBS) coding scheme were adopted and developed as the research method to analyse participants' cognitive behaviours. Preliminary results identify the cognitive changes that differentiate SMM from AMM as well as the impact of switches in design processes. These are discussed in this paper.

RELATED DESIGN STUDIES

Providing solutions that effectively meet the requirements of design briefs is the ultimate goal of designers. A creative design process is best defined by its output - creative design processes produce great design outcomes (Sobek II and Jain, 2004). Teaching students about creative design processes is a common goal of many architectural design courses worldwide. The earliest phase of the design process focuses on understanding the problem at hand and making decisions about solutions (Cross and Dorst, 1999). This phase, referred to as conceptual design, has a significant impact on detailed design, cost and construction. Some methodological studies about this phase, such as the synectics method (Gordon, 1961) and the brainstorming method (Osborn, 1963), highlight the importance of sketching or drawing to illustrate concepts. Sketching has been intensively studied in early architectural design, where individual designers begin to develop their conceptual designs for a building by sketching a plan, elevation, or a view of a building (Eckert et al., 2010) or by making unexpected discoveries about design problems (Suwa et al., 2000).

Research on sketching design environments

Sketching is used not only to communicate the results of architectural design to clients, users, legislators and constructors, but also as a central tool in the design process (Lawson, 2002). Sketching plays a pivotal role in the initiation and development of creative ideas during the early design phase. Designers rely on it to support and accentuate the visual reasoning necessary to explore the spatial relationships between diagrams. The design problem space evolves from an ill-defined problem to the identification and resolution of creative ideas when designers interact with sketches.

Sketching makes an important contribution to the design process. Initially designers brainstorm as many ideas as possible. Sketching is central to this process as raw sketches can be easily generated, revised, refined and consolidated as ideas are developed. Consequently, sketches act as a conceptual tool for designers, supporting and stimulating creative ideas (Goldschmidt et al., 1992). Suwa and Tversky (2001) argue that professional designers use sketching to generate new ideas, rather than to simply express current ideas. They observe that the simple process of re-examining old sketches, including one's own and others' can lead to unexpected discoveries that generate new ideas.

Although sketching offers flexibility, is quick and encourages intuitive interactions, making its use popular amongst designers in the early design phase (Gross and Do, 1996), sketching can interrupt the flow of the design process especially when designs need to be transferred to CAD. To readily transfer sketches into CAD, designers are increasingly using computer program applications like ArchiCAD in the early design stage. Furthermore, the increasing globalisation of projects in AEC has complicated design processes, rendering conventional sketching tools largely inadequate. Consequently, CAD modelling is increasingly being used in complex projects because it provides the additional benefit of digital representation and communication for future analyses and process integration.

Research on CAD design environments

The expressive and geometric power of CAD modelling has increased to such an extent that it can be used by itself from beginning to end to achieve design goals. This approach replaces traditional methods such as sketching and can be termed a digital design process. Although traditional sketching methods are low cost, 2D representations may not convey ideas about complex 3D objects. For example, sketches are imprecise when multiple 2D views are used to produce a 3D perspective. In a CAD modelling design environment, 3D graphics (e.g. perspective views) can be employed to generate and manipulate 3D geometry (Aish, 1986). CAD modelling can be meaningfully used to support problem-solving in the design process. Conventional approaches involve sketching as a means of representing basic conventions, but these are inadequate for solving complex problems (Lin, 2001).

More recently, CAD modelling has proved to be effective across the whole range of AEC practices. Designers and clients use CAD models to review and evaluate building designs before construction. This provides them with opportunities to make substantial changes at a reasonable cost. Engineers use CAD models to evaluate structural alternatives (Reffat, 2002). Industry professionals use CAD models to estimate costs and to plan for cost-effective construction sequences. These processes frequently unearth design conflicts that would otherwise result in expensive construction defects. For existing buildings it is often desirable to use CAD models to analyse energy properties, to explore how a potential fire could spread, to explore potential changes in a building, and to increase the possible uses of existing building spaces (Lewis and Sequin, 1998). Some argue that cost savings of at least 30% are possible if the design and construction industry commits itself to complete CAD modelling (BSS, 1997). Moreover, the accurate visualisations possible with CAD modeling may help designers to alter and refine their design thinking (Salman et al., 2014).

There are thus clear advantages to using CAD to support design processes, and researchers continue to seek ways to integrate sketching and CAD modelling into one design medium to improve the conceptual design phase.

Research on mixed media design environments

In recent years research has shifted from single design mediums to the influence of mixed media on cognitive activities during the conceptual design phase. Evidence for the use of mixed media comes from Sachse et al. (2001) who surveyed more than 100 expert designers who used sketching prior to and concurrently with CAD modelling. Their study identified three positive outcomes of this approach: better solutions, faster task completion, and fewer processing steps to develop CAD models. These results are supported by Chen (2007) who studied design creativity by using conventional and digital media simultaneously. The results showed that as designers switch from sketching to digital tools, design creativity is stimulated because switching behaviour causes designers to re-think previous ideas and to improve the quality of their designs.

Ibrahim and Rahimian (2011) argued that the CAD software available at the time did not facilitate the intuitive aspects of conceptual design. Therefore they introduced the concept of mixed media which is an integration of sketching and CAD modelling. They conducted a protocol study of architectural students in three discrete design environments, mixed media, sketching and CAD modelling, and found mixed media to be the most effective external representation tool because it generates higher quality solutions than either CAD modelling or sketching.

Interaction between sketching and CAD modelling encourages switching behaviour that may have the potential to impact on design processes. These mixed media studies underpin further research which compares cognitive behaviour in SMM and AMM design environments.

RESEARCH METHODOLOGY

The credibility of a study depends upon the research method chosen and the way in which the research is conducted. Different ways of using sketching and CAD modelling in design provide various benefits. Determining which methods were the most appropriate for the research questions of this study was challenging. Sketching and CAD modelling remains a natural design process and is considered to be a real phenomenon. A major difficulty in mixed media research is the methodological problem of identifying the function and properties of each method and the underlying operations in the cognitive study. Another major difficulty is that of identifying switching processes between the sketching and CAD modeling.

Different approaches have been taken to study designers (Cross, 2001) including interviews with expert designers (Cross, 1999; Cross and Cross, 1995), observations and case studies (Candy and Edmonds, 1996), stimulation trials (Gero and Sudweeks, 1998) and protocol studies (Akin 1993; Pour Rahimian et al., 2011; Suwa and Tversky 1997; Tang et al., 2011). Studying mixed media in design is more difficult than studying individual design environments (Kan and Gero, 2008; Suwa and Tversky, 1997; Tang et al., 2011). In addition, the SMM approach can easily be frustrated when switching between media is prohibited and there is no reliable method of analysing the impact of switching behaviour.

Protocol analysis offers a potentially effective method for the controlled observation and experimental analysis of cognitive behaviour (Akin 1993; Candy et al., 2006). Protocol analysis can be used to help understand the design process of designers, the knowledge they use, the cognitive actions they take and the strategies they employ. An application of protocol analysis is to ask designers how they design an artefact. However, they usually find this question difficult to answer in detail. This is because designers often store their design thinking in their short-term memory while designing. Another possibility is to look at their sketches, notes or CAD models, but without further information it is difficult to understand their design processes. Many studies (Akin 1986; Ibrahim and Rahimian 2011; Suwa and Tversky 1997; Tang et al., 2011) show that protocol analysis can record almost all information about designers' reasoning during the design process rather than simply relying on their design results for such insights.

There are two ways to report protocol data: retrospective and concurrent (think-aloud) verbailisation (Doorst and Dijkhuis, 1995). Generally, retrospective verbalisation means that designers perform tasks and are questioned afterwards about their thought processes during their design. Another approach is to video design sessions and to review recordings together with the designers enabling them to interpret what happened. However, it may be difficult to remember thought processes after an activity has been completed and the usefulness of this method is limited (Newell, 1990). Another problem is that designers may present their thought processes as more coherent and intelligent than they originally were; they may not report thoughts they actually had during the design process and may instead report false memories. This may give a false impression of perfectly rational behaviour (Newell, 1990). Designers' retrospection means that information must be retrieved from long-term memory and then verbalised. The disadvantage of this approach is that the retrieval process may not unearth all the information that was actually experienced in short-term memory during the design processes.

On the other hand, the think-aloud protocol requires designers to verbalise his / her thoughts while designing (Tang, 2001; Van Someren et al., 1994). In other words, designers explain their thoughts whilst performing the task at hand. Unlike retrospective protocols for gathering verbal data, no set questions are asked. Designers are encouraged to give a concurrent account of their thoughts and to avoid interpreting what they are doing (Gero and Tang, 2001). This method is more successful because almost all of a designer's conscious effort is aimed at achieving the design task. This restricts the opportunities for them to reflect on their design activities. As such, the data gathered are very direct; there is no delay that can result in altered data. The advantages of concurrent verbailisation fit the aim of this research because this process focuses on analysing actual designers' cognitive actions rather than using subjective self-reports (Salman et al., 2014). Therefore, concurrent verbalisation was selected for this study.

Generally, protocol studies involve the following steps (Ericsson and Simon, 1993; Kan and Gero, 2008): (1) Proposing a research direction/gap; (2) Participant recruitment and experiment set-up; (3) Conducting/recording the experiment; (4) Transcribing protocol data; (5) Development of a coding scheme; (6) Encoding the protocol data; (7) Analysis of the protocol data; and (8) Interpretation of results. The most important step is to propose an appropriate coding scheme that reveals meaningful research outcomes. The study reported here has two purposes; firstly, to explore whether the experimental design is effective in producing desired outcomes and, secondly, to test whether meaningful results emerge from the coding scheme. Depending on the preliminary results, the experimental design and the coding scheme may be revised. The next section introduces the FBS coding scheme and a justification for this study.

Justification of FBS coding scheme for mixed media design study

Gero's Function-Behaviour-Structure (FBS) framework was developed in 1990 (Gero, 1990) and has evolved over the last two decades. Many protocol design studies have adopted the FBS model to describe design processes and tasks (Gero and Kannengiesser, 2004). Some researchers argue that the definition of function has not been stable over the years and that the FBS model both describes actual designing and prescribes improved designing (Tang et al., 2011). Thus, the definition of FBS has been revised to encompass these nuances. The FBS coding scheme is defined as a process-oriented design theory in which designing is understood as a sequence of distinguishable stages.

The FBS coding scheme (Figure 1) situates designing in terms of six design issues: requirements, functions, expected behaviours, behaviours derived from structures, structures and documentation. The goal of designing is to transform a set of requirements (R) into a set of design documents (D). The function (F) of a designed object is defined as its purpose or teleology. The behaviour (B) of that object is how it achieves its functions and is either derived (Bs) or expected (Be) from the structure. The structure (S) comprises the elements of an object and their relationships. A design description is never transformed directly from the function but undergoes a series of design processes among the FBS design issues. These design processes include: a formulation (F→Be) which transforms functions into a set of expected behaviours; a synthesis (Be →S), wherein a structure is proposed that is likely to exhibit the expected behaviour; an analysis (S→Bs) of the structure which produces its derived behaviour; an evaluation process (Bs⇆Be) which acts between the expected behaviour and the behaviour derived from structure; and documentation (S→D), which produces the design description (Gero and Kannengiesser, 2004; Gero and McNeill, 1998). Depending on the structure, there are three types of reformulation, where new variables are introduced: reformulation of structure (S→S), reformulation of expected behaviour (S→Be), and reformulation of function (S →F). Reformulation of function is relatively rare, as it changes or redefines the design problem (Gero, 1990).

The FBS coding scheme has been used as a uniform framework to represent and classify design processes in numerous studies. A recent example compared the design processes of ten groups in a traditional sketching environment and in a digital sketching environment, encoding their protocol data using the FBS coding scheme. The transcribed protocol data needed to be divided into small segments to facilitate the coding process. Both the content of the segments and the transitions between segments in each environment were analysed statistically (Tang et al., 2011). The results revealed that the design processes used in digital and traditional environments were similar in terms of the speed of the design process and design issues involved. Moreover, Kan and Gero (2005) undertook a design study demonstrating that the FBS coding scheme can be used to compare different forms of collaborative design, such as face-to-face and virtual environments. They found two different processes of formulation and reformulation. The primary advantage of the FBS coding scheme is that it clearly shows the relationships between the eight design processes and the six design issues. It is an effective coding scheme for analysing design activities in SMM and AMM design sessions.

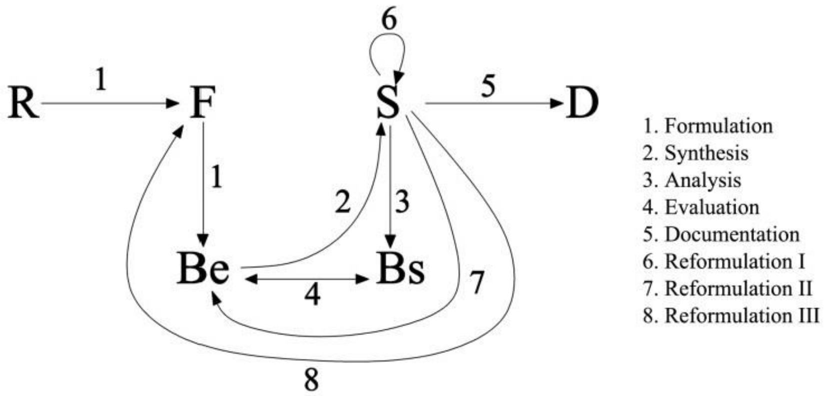


Figure 1. FBS coding scheme (Source: Gero and Kannengiesser, 2004)

Development of FBS coding scheme for mixed media design study

This study explored cognitive behaviour in mixed media design environments in contrast to other research (Bilda and Gero, 2006; Suwa and Tversky, 1997; Suwa et al., 2000) which studied cognitive behaviour in single design environments. Both sketching and CAD modelling facilitate design processes as external aids. A coding scheme structure was used to distinguish the cognitive behaviour in mixed media design environments (Figure 2). Based on the FBS coding scheme, both sketching and CAD modelling design environments consist of six design issues (R, F, Be, Bs, S, and D) to enable different distributions of design issues to be collected and analysed.

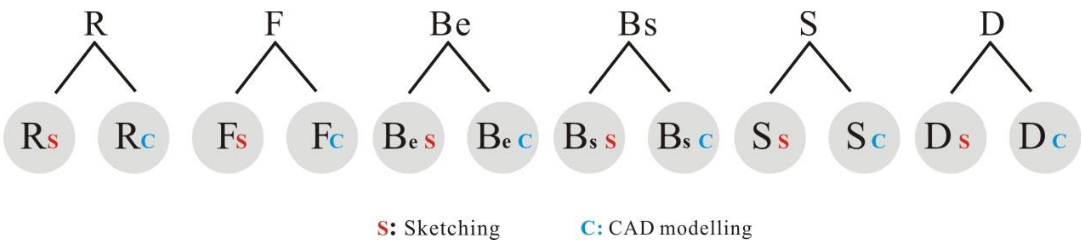


Figure 2. Development of FBS coding scheme for SMM and AMM sessions

This study provides a reference frame of the six design issues of the FBS coding scheme to calibrate the protocol segmentation and a coding process for SMM and AMM sessions (Table 1). Requirements (R) are usually imposed on design processes by external agents, like clients and regulations, rather than consciously by designers. In the study, the majority of the requirements were provided in the design brief and the site plan, presenting constraints not determined by the designers. However, designers consider other constraints in the process of producing their designs. As the function (F) refers to the purpose of design, the ‘function issues’ refer to a designer’s articulation of what a design brief requires, such as different functions of spaces and buildings. Behaviour (B) refers to what the artefact does and consists of expected behaviours (Be) and behaviours derived from structures (Bs). The distinction between Be and Bs is then made by examining whether a specific behaviour is the result of designers' expectations (future consequences) or a derived consequence from a structure (previous consequence). Structure (S) refers to an artifact defined as its components and their relationships, i.e. what the artifact consists of. Structure may also refer to physical features of the designed building, such as size, proportion, height, and material. Documentation (D) refers to external representations that designers use to express their thoughts, including writing or sketching on paper, and editing CAD models.

Table 1: Examples of using FBS coding scheme in mixed media environments

Design issues	Code	Example transcripts	Explanation
Requirement (R)	Rs	look at the template to see where I am (using sketching)	task requirement from original plan
	Rc	go back to design brief (using CAD modelling)	task requirement from design brief
Function (F)	Fs	kitchen can be kitchen again (using sketching)	designer's articulation of what design briefs want
	Fc	extend a wall between kitchen and meeting room for creating a small kitchen (using CAD modelling)	designer's articulation of what design briefs want
Behaviour (Be) and (Bs)	Bes	try evaluation of two offices (using sketching)	'try' suggests this behaviour is an expectation (Be)
	Bsc	light coming from north (examine a CAD model)	derived consequence from a structure (Bs)
Structure (S)	Ss	we can have a stair there (using sketching)	propose a component
	Sc	maybe distribute six pieces of glass (using CAD modelling)	refer to physical features
Documentation (D)	Ds	write down key words of design brief on the paper, reception area…for (using sketching)	documentation of Functions
	Dc	now I get rid of the roof (using CAD modelling)	editing CAD models

Designing the experiment

Protocol analysis can be used for a single designer, or a team of designers. Two architectural designers were recruited as participants in the study. They were initially identified from those who could best satisfy the selection criteria. To be included, the participants needed: (1) a tertiary degree in architecture with a minimum of one-year of professional architectural practical experience; (2) a design degree that had been obtained within the last three years so that participants had similar professional architectural practice experience; (3) competence in both sketching and CAD modelling; and (4) competence in practising and communicating design in English.

Another challenge in experimental settings is the development of an appropriate design task to achieve the research aims. Normally a 50 to 75 minute protocol task can produce sufficient data and a manageable protocol size (Dorst, 1996). Dorst (1996) proposed that design tasks be challenging, realistic, appropriate, not too large, feasible in the time available and within the scope of knowledge of the researchers. Architectural designers often design buildings and this study provided existing models of buildings, including a 2D layout and CAD models (Figure 3). Participants were asked at random to use the models to design a building for different purposes: an architectural office, a dream house, and an art gallery. These tasks were appropriate as existing building models were used, and the task could be completed within 75 minutes. The challenge was to use the 2D layout and the 3D model to design for different purposes. In SMM design sessions, the participants worked on the 2D layout by sketching, followed by CAD modelling; while, in AMM sessions, the participants were allowed more freedom and could use both sketching and CAD modelling at will.

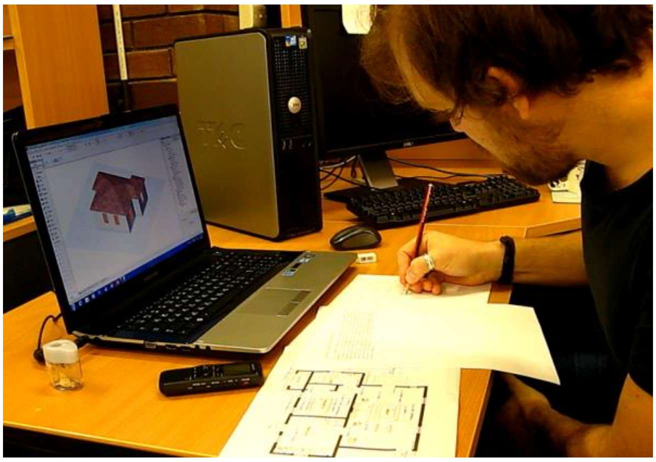
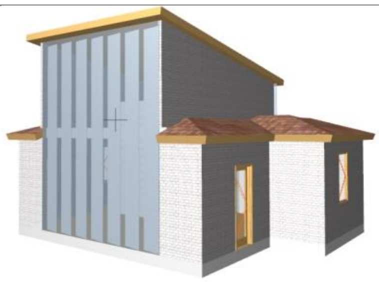


Figure 3. Participant worked on an existing house CAD model and 2D layout

PRELIMINARY RESULTS AND ANALYSES

The results of the study were drawn from SMM and AMM experiments (Table 2).

Table 2: Overview of SMM and AMM experimental designs

	Participant-A	Participant-B
Design briefs for SMM	Art Gallery Design	Architectural Office Design
Total time	65 minutes	70 minutes
Task completion	Yes	Yes
Their outcomes		
Design briefs for AMM	Architectural Office Design	Dream House Design
Total time	58 minutes	62 minutes
Task completion	Yes	Yes

Their outcomes		

Appropriate design protocols for the study included recording all forms of the designers' overt behaviours, such as verbalisation, sketching, CAD modelling, and switching between media. This resulted in missing switching protocols. Table 3 shows examples of the FBS codes of the AMM protocol without switching interviews.

Table 3: Example codes of the AMM protocol without interviews

Numbers	Context	Code	Notes
25	think about circulation of the door	Fs	N/A
26	draw an arrow	Ds	N/A
27	check the CAD model with views of different angles	Bsc	N/A

Table 4 shows examples of design switches including 'eye' and 'eye with hand' from sketching to CAD modelling, and from CAD modelling to sketching. Participants were interviewed after completing AMM sessions and asked to identify and explain their reasons for switching media by looking at their videos of AMM design processes.

Table 4: Examples of the participants' switches

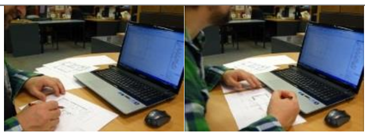
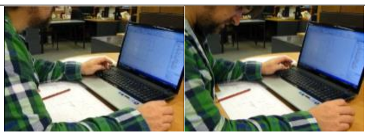
Design switches	Types	Participant-A	Participant-B
Sketching→ CAD modelling (S→C)	Eye		
	Eye and hand		
CAD modelling →Sketching (C→S)	Eye		
	Eye and hand		

Table 5 shows the inclusion of interview excerpts as new segmentations. This enabled the FBS codes to be contextualised. For example, the code (no.28) of segment 'check the CAD model with views of different angles' was revised from Bsc to Dc to acknowledge the impact of the switch noted in the interview.

Table 5: Example codes of the AMM protocol with switch interviews

Numbers	Context	Code	Notes
25	think about circulation of the door	Fs	N/A
26	draw an arrow	Ds	N/A
27 Insert the switch-1	Once the sketching design process was completed through sketching I moved it to the CAD model to realise the design completed through the sketching process. Using the sketched design as a reference point to help the design to be completed in the CAD environment.	Dc	(S→C) insert switch interviews
28	check the CAD model with views of different angles	Dc	Bsc→ Dc

Comparison FBS design issue distributions between SMM and AMM sessions

A high level of agreement was achieved between arbitrated protocols. Two rounds of coding were conducted during a two week period (Gero and McNeill, 1998). The coding consistency shown in Table 6 demonstrates that the coding was reliable.

Table 6: Summary of segmentation and coding results

Participants	Sessions	Coding 1 vs. Arbitrated (%)	Coding 1 vs. Arbitrated (%)
Participant - A	SMM	76.5	84.8
	AMM	74.1	86.3
Participant - B	SMM	77.2	82.7
	AMM	72.8	85.4

Since the design sessions and participants varied, the study normalised the frequency distribution of design issues by converting to occurrence percentages (Figure 4). Participant-A and participant-B produced quantitatively similar distributions for design issues in SMM and AMM. The six design issues were divided into three groups in the following order: structure (S) and documentation (D) > behaviour derived from structure (Bs), expected behaviour (Be) and function (F) > requirement (R). In AMM design sessions, documentation (D) of participant-A was significantly higher than that of participant-B (34.1% > 12.5%). In contrast, requirement (R) of participant-B was significantly higher than that of participant-A (11.8% > 3.2%). These changes demonstrate that participants' switches may have impacted on their design processes in AMM sessions.

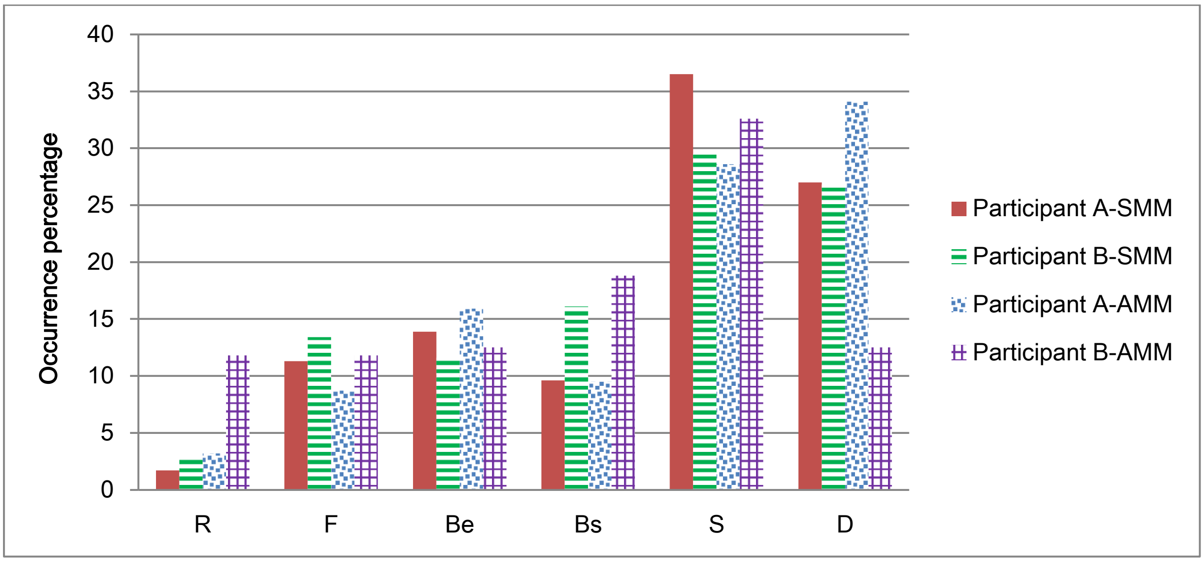


Figure 4. Design issue distributions of participant A and B in SMM and AMM sessions

Figure 5 presents the aforementioned two design issue distributions in sketching and CAD modelling in SMM and AMM design sessions. A comparison of the two participants' results shows that the total distribution of documentation (D) in SMM is similar as is the percentage for using sketching and CAD modelling. On the other hand, participant-A produced a higher percentage on documentation (D), and a higher percentage on sketching and CAD modelling distributions than participant-B. There are a number of reasons why participant-A's switches changed the design issues from structure (S) to documentation (D) when switching from sketching to CAD modelling: 'Transferring the sketch plan to the CAD environment' and 'Then moved it onto CAD', as defined for the first type of design switch (S→C) in the context of the paper. Referring to Table 1, the segment for making a new component in CAD should be coded as structure (Sc). However, for the reasons mentioned above, for design switch (S→C), the same segment will change to documentation (Dc) because the participant transferred sketches into CAD.

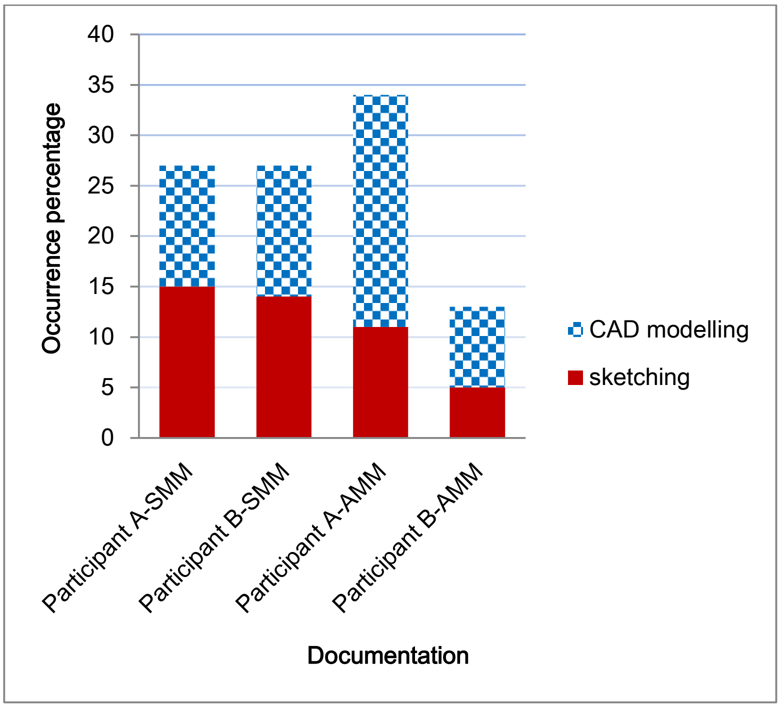


Figure 5. Documentation distributions of participant A and B in sketching and CAD modelling

Figure 6 shows how participant-A facilitated the design process when switching between media. First of all, the participant found it challenging to locate an appropriate place for a stair using CAD. The participant therefore switched to sketching (C→S) to refine and evaluate different locations. Once satisfied, the participant transferred the sketches in CAD (S→C).

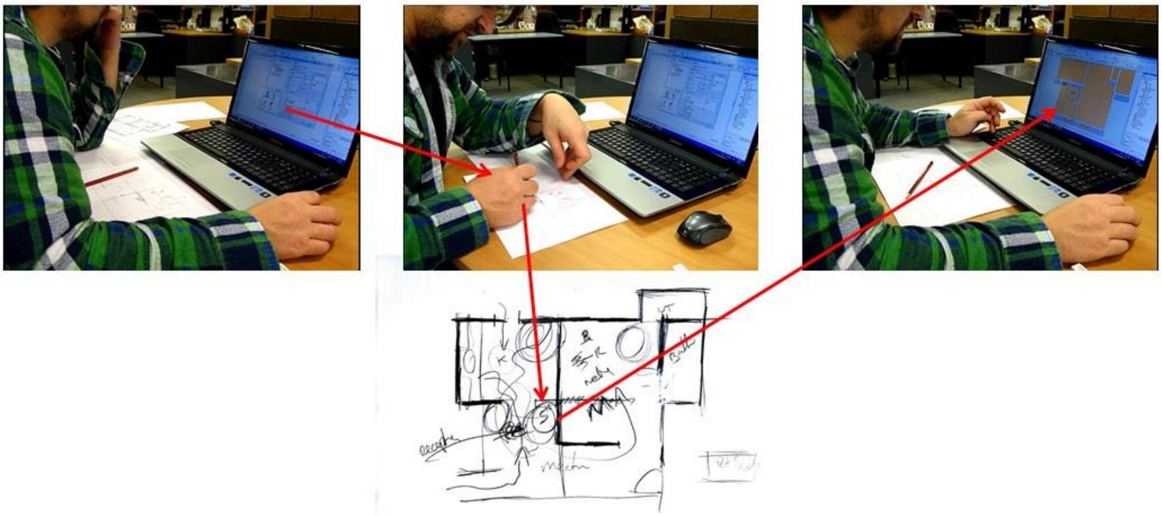


Figure 6. Examples of participant-A design switches

Figure 7 shows that participant-B produced the highest percentage for requirements (R) because of regularly switching between media and the design brief. The reasons given included:

'I moved from sketching to the CAD environment because I wanted to start designing in a virtual setting to understand the spatial and scale requirements of the brief. I noted that as

the 3D model is readily available, I can begin to make immediate changes to form the new design proposal';
'I noted that I was cross-checking the requirements of the brief so I can keep on task with my current design intentions'; and
'In the final stages of completion, I noted that I was switching back and forth so I can check that I have satisfied the requirements of the set brief',

The participant was switching back and forth between sketching/CAD modeling and design brief, as defined for the second type of design switch (S/C⇆R) in the context of the paper. In addition, this type of design switch refers to Cross and Drost (1999) and Suwa et al. (2000)'s protocol studies such as 'situative invention (S-invention)' and 'co-evolution'. Cross and Dorst (1999) posited the modelling of design creativity as a co-evolution for both problem and solution spaces. According to Suwa et al. (2000), S-invention refers to designers' activities that extend beyond the initial definitions of the problem-space, helping designers to form new goals to address significant parts of design problems.

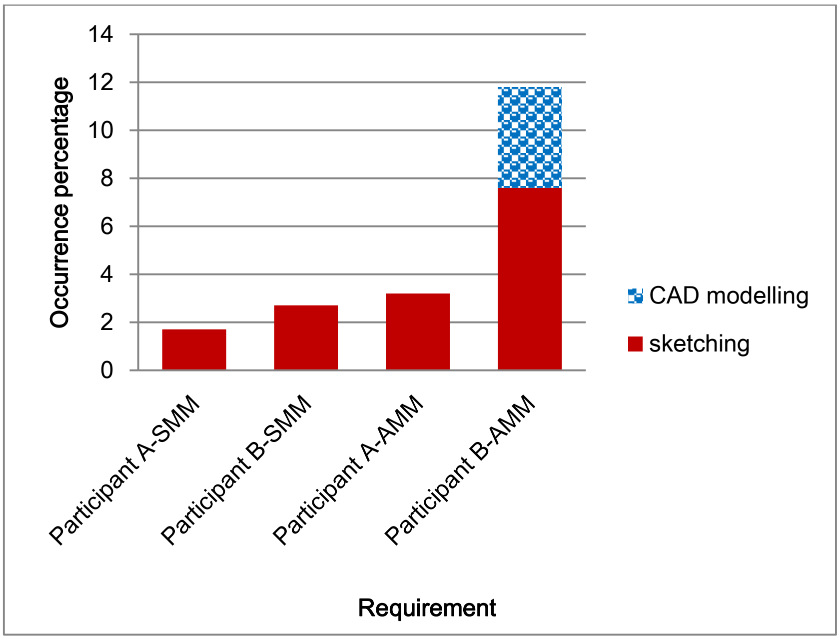


Figure 7: Requirement distributions of participant A and B in sketching and CAD modelling

DISCUSSION

In general, sketching allows design solutions to be stored and subsequently evaluated. This helps designers recognise different design possibilities (Akin, 1978). By contrast, it is not possible to store alternatives on a screen when CAD modelling is used. Designers need to undo and redo their CAD models when changes are required. The two design processes, SMM and AMM, may lead to changes in the roles of design mediums. Using AMM (i.e. being able to switch between media) allows designers to engage effectively in their design processes and find appropriate solutions to problems. For instance, Figure 6 shows that participant-A was fully engaged in design processes using AMM. However, participant-A mentioned 'I get stuck' several times during CAD designing section when using the SMM approach.

Participants' comments

Participants provided comments on completion of both experiments. Their feedback about SMM was that they would not be capable of designing using CAD if they were not allowed to switch. The common view was that if they were allowed to switch between media they would have evaluated their ideas quickly at both abstract and concrete levels. On the other hand, completing activities in AMM design environments were likened to tracing ideas between sketching and CAD modelling. Their view was that by switching between media they were able to complete their design tasks smoothly. This relates to the concept of the ‘right-tool-right-time’, (Do, 2005: 396) and that such usage would actually engage participants thinking along creative pathways.

All participants believed strongly that switches were essential. They summarised the contribution of being able to switch as follows:

1. Switching is essential: ‘I think the combination of sketching in tandem with CAD tools offers the designer a great freedom of design expression, having the ability to cognitively work between two mediums. This process of switching mediums, in my opinion, is the ideal design format for conceptualisation’.

2. Switching is a natural design workflow: ‘Many designers use sketching, mostly as visual notes, to rapidly memorise a design idea. CAD is useful to record the ideas and extend the development of the visual notes taken whilst thinking about the design and reflecting upon the design requirements. Using CAD as a permanent record of design ideas that are ever changing on paper helped me stabilise the design workflow. For me personally it was easy and natural to switch between mediums as it forms a very natural and complimentary workflow’.

3. Switching has potential for creative engagement with interactive mediums: ‘I found it quite natural to work in the AMM session, I felt I could achieve better results by sketching first and then going back to alter in tandem with the CAD tools provided’.

Categorisation of three types of switching between media

While Table 4 and Figure 6 demonstrated several design switches between media, the results of the study can be categorised into three types of switches:

1. The first type of design switch, from sketching to CAD modelling (S→C), changes a design issue of the FBS coding scheme from structure (S) to documentation (D): ‘I was trying the hand-sketched design in the CAD environment so as to better understand its function in terms of scale, section and elevation’ and ‘moved it onto CAD’.

2. The second type of design switch, back and forth between sketching/CAD modeling and design brief (S/C⇆R) within seconds, evaluates the similarities and differences between sketches/CAD models and design briefs which was coded as requirements (R): ‘I was switching back and forth so I can check that I have satisfied the requirements of the set brief’.

3. In the third type of design switch, from CAD modelling to sketching (C→S), the participants preferred using sketching to refine their ideas than using CAD modelling: ‘I was sketching another spatial variation of the floor plan to better understand the spatial qualities at a conceptual level’.

Implications for design research and practice

This study compared cognitive behaviour in SMM and AMM design environments. It provides empirical evidence to better understand two approaches of integrating sketching and CAD modelling. The FBS coding scheme was developed to fit mixed media design environment studies and allow researchers to compare overall design processes as well as changes of cognitive behaviour within indiviual design mediums. The development of coding schemes and the techniques of combining these with switching protocols are transferable for future investigations about the integration of design mediums.

The empirical results suggest that switching is essential. It is a natural design process and has the potential to generate creative engagement with interactive media to help participants achieve better design outcomes. The three types of switches, S→C, S/C⇆R and C→S, serve different roles for participants to facilitate their designs. It is likely that preventing participants from switching for more than one hour would have resulted in an excessive cognitive load which would have resulted in frustration and inertia. The switches between media require much less cognitive design process load.

CONCLUSION

The main question addressed in this study was whether participants' switches between sketching and CAD modelling influence design processes. First, the results show that the designers switched many times between sketching and CAD modelling during AMM design processes. Second, two design issues (S and Bs) of the FBS coding scheme were changed to design issue (D) after switching from sketching to CAD modelling (S→C). A possible mechanism by which designers' switches influence design processes is Do's concept of 'right-tool–right-time', (Do, 2005: 396). This also supports Coyne et al.'s (2002) research with respect to the integration of conventional and digital methods for sketching: each is valued rather than one replacing the other. Some studies of cognitive behaviour (Chen, 2007; Ibrahim and Rahimian, 2011) have found mixed media to be the most effective external representation aids because they generate higher quality solutions than when CAD modelling is used in isolation. However, most participants in these studies were asked to initially use sketching before shifting to CAD modelling. Interestingly, in the study reported here, it was observed that both participants spent more time on CAD modelling than sketching. One advantage of this study is the AMM experimental set-up, which is close to the circumstances of natural design. In conclusion, this study has demonstrated that both participants' switches were effective in influencing design processes because the switches integrated both sketching and CAD modelling as one design medium.

The current study is based on the two participants' protocols in the SMM and AMM sessions combined with interviews about switching. These activities produced a large amount data and provided opportunities to test various experimental settings. However, the sample size of this study is more modest than other protocol design studies. To better understand mixed media studies, further investigations with a larger sample size will be conducted.

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REFERENCES

Aish, R. (1986). Three-dimensional Input and Visualization, *Computer-Aided Architectural Design Futures, CAAD Futures Conference Proceedings*, 68-84.
Akin, O. (1993). Architects' Reasoning with Structures and Functions, *Environment and Planning B: Planning and Design*, 20, 273-294.
Akin, O. (1986). *Psychology of Architectural Design*, London: Pion.
Bilda, Z., & Gero, J. S. (2006). To Sketch or Not to Sketch? That is the Question. *Design Studies*, 27(5), 587-613.
BSS (1997). The Third Eye, *Building Services Supplement*, May, 8-9.
Candy, L, Bilda, Z, Maher, ML & Gero, JS (2004). Evaluating Software Support for Video Data Capture and Analysis in Collaborative Design Studies, *Proceedings of QualIT04 (Qualitative Research in IT and IT in Qualitative Research) Conference,* Brisbane, Australia, CD-rom, no page numbers.
Candy, L. & Edmonds, E. (1996). Creative Design of the Lotus Bicycle. *Design Studies*, 17(1): 71-90.
Chen, Z. R. (2007). How to Improve Creativity: Can Designers Improve Their Design Creativity by Using Conventional and Digital Media Simultaneously? *CAAD Futures 2007*, *Proceedings of the 12th International CAAD Futures Conference*, 571-583.
Coyne, R., Park, H., & Wiszniewski, D. (2002). Design Devices: Digital Drawing and the Pursuit of Difference. *Design Studie*s, 23(3), 263-286.
Cross, N. (1999). Natural Intelligence in Design, *Design Studies*, 20, 25-29.

Cross, N. (2001). Achieving Pleasure from Purpose: The Methods of Kenneth Grange, Product Designer. *Design Journal*, 4(1), 48-58.
Cross, N. & Cross, A. (1995). Observations of Teamwork and Social Processes in Design, *Design Studies*, 16(2), 143-170.
Cross, N., & Dorst, K. (1999). Co-evolution of Problem and Solution Space in Creative Design, in J. S. Gero and M.L. Maher (eds.) Computational Models of Creative Design IV, Key Centre of Design Computing, University of Sydney, 243-262.
Do, E. Y. L. (2005). Design Sketches and Sketch Design Tools, *Knowledge Based Systems* (18) 383-405.
Dorst, K. (1996). The Design Problem and its Structure, in N. Cross, H. Christianns and K. Dorst (eds.), *Analysing Design Activity*, Chichester and New York: John Wiley, 17-35.
Dorst, K. & Dijkhuis, J. (1995). Comparing Paradigms for Describing Design Activity, *Design Studies*, 16(2), 261-275.
Eckert, C. M., Blackwell, A.D., Bucciarelli, L.L., & Earl, C. F. (2010). Shared Conversations Across Design. *Design Issues*, 26(3), 27-39.
Ericsson, K. A. & Simon, H. A. (1993). *Protocol Analysis: Verbal Reports as Data,* Cambridge, Mass: MIT Press.
Ehrlenspiel, K. (1995). *Integrierte Produktentwicklung*, München: Hanser.
Gero, J. S. (1990). Design Prototypes: A Knowledge Representation Schema for Design. *AI Magazine*, 11(4), 26-36.
Gero, J. S., & Kannengiesser, U. (2004). The Situated Function-Behaviour-Structure Framework, *Design Studies*, 25(4) 373-391.
Gero, J. S., & McNeill, T. (1998). An Approach to the Analysis of Design Protocols. *Design Studies*, 19(1), 21-61.
Gero, J. S. & Sudweeks, F. (1998). *Artificial Intelligence in Design '98*, Dordrecht: Kluwer.
Gero, J. S. & Tang, H. (2001). The Differences Between Retrospective and Concurrent Protocols in Revealing the Process-oriented Aspects of Design Protocols. *Design Studies*, 19(1), 21-61.
Gross, M. & E. Y., Do. (1996). Ambiguous Intentions: A Paper-Like Interface for Creative Design. *Proceedings of the ACM UIST Conference*, 183-192.
Goldschmidt, G. (1995). Visual Displays for Design: Imagery, Analogy and Databases of Visual Images, in Koutamanis, A., Timmermans, H. and Vermeulen, A. (eds), *Visual Databases in Architecture; Recent Advances in Design and Decision Making,* Aldershot: Avebury, 53–74.
Gordon, W.J.J. (1961). Synetics: The development of creative capacity, New York, Harper and Row.
Goulding, J. S., Pour Rahimian, F., & Wang, X. (2014). Virtual Reality-based Cloud BIM Platform for Integrated AEC Projects. *Journal of Information Technology in Construction (ITCON)*, 19(Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends), 308-325.
Ibrahim, R., & Rahimian, F. P. (2011). Comparison of CAD and Manual Sketching Sools for Teaching Architectural Design. *Automation in Construction*, 19(8), 978-987.
Kan, J. W. T. & Gero, J. S. (2005). Can Entropy Indicate the Richness of Idea Generation in Team Designing? *Proceedings of the 10th International Conference on Computer Aided Architectural Design Research in Asia* (*CAADRIA 2005*), New Delhi, India.
Kan, J. W. T. & Gero, J. S. (2008). Acquiring Information From Linkography in Protocol Studies of Designing. *Design Studies*, 29(4), 315-337.
Lawson, B. R. (2002). CAD and Creativity: Does the Computer Really Help? *Leonardo*, 35(3), 327-331.
Lewis, R. & Sequin, C. (1998). Generation of 3D Building Models from 2D Architectural Plans, *Computer-Aided Design*, 30(10), 765-779.
Lin, C. (2003). Seeing Moving Seeing Model for Computer Media, *8th International Conference on Computer Aided Architectural Design Research in Asia,* Bangkok, 199-208 .
Newell, A. (1990). *Unified Theories of Cognition*. Cambridge, Mass: Harvard University Press.
Osborn, A. F. (1963). *Applied Imagination: Principles and Procedures of Creative Problem-Solving*. New York: Scribner.
Pour Rahimian, F., Ibrahim, R., Rahmat, R. W. B. O. K., Abdullah, M. T. B., & Jaafar, M. S. B. H. (2011). Mediating Cognitive Transformation with VR 3D Sketching During Conceptual Architectural Design Process. *Archnet-IJAR, International Journal of Architectural Research*, 5(1), 99-113.

Reffat, R. (2002). Three-Dimensional CAD Models: Integrating Design and Construction, in R. Best and G. de Valence (eds), *Innovation in Design and Construction: Building in Value*, Oxford: Butterworth Heinemann, 291-305.
Robbins, E. (1994). *Why Architects Draw*, Cambridge Mass: MIT Press.
Romer, A., Pache, M., Weißhahn, G., Lindemann, U. & Hacker, W. (2001). Effort-Saving Product Representations in Design-Results of a Questionnaire Survey. *Design Studies*, 22(6), 473-491.
Sachse, P., Leinert, S. & Hacker, W. (2001). Designing with Computer and Sketches, *Swiss Journal of Psychology*, 60(2), 65-72.
Salman, H. S., Laing, R. & Conniff, A. (2014). The Impact of Computer Aided Architectural Design Programs on Conceptual Design in Educational Context. *Design Studies*, 35 (4), 412-439.
Schön, D. A. (1992). Designing as Reflective Conversation with the Materials of a Design Situation, *Knowledge-Based System*, (5.1), 3-14.
Sobek, II, D. K., & Jain, V. K. (2004). Two Instruments for Assessing Design Outcomes of Capstone Projects, *Proceeding of the 2004 American Society for Engineering Education Conference and Exposition*.
Suwa, M. & Tversky, B. (2001). How Do Designers Shift Their Focus of Attention in Their Own Sketches? In Anderson, M., Meyer, B. and Olivier, P. (eds.) *Diagrammatic Reasoning and Representation*, Berlin: Springer, 241-260.
Suwa, M., & Tversky, B. (1997). What do Architects and Students Perceive in Their Design Sketches? A Protocol Analysis, *Design Studies*, 18(4), 385-403.
Suwa, M., Gero, J., & Purcell, T. (2000). Unexpected Discoveries of Design Requirements: Important Vehicles for a Design Process, *Design Studies*, 21(4), 539–567.
Tang, H. (2001). *Exploring the Roles of Sketches and Knowledge in the Design Process*. PhD thesis. The University of Sydney, Department of Architectural and Design Science. Faculty of Architecture.
Tang, H. H., Lee, Y. Y., & Gero, J. S. (2011). Comparing Collaborative Co-Located and Distributed Design Processes in Digital and Traditional Sketching Environments: A Protocol Study Using the Function-Behaviour-Structure Coding Scheme. *Design Studies*, 32(1), 1-29.
Van Someren, M. W., Barnard, Y. F., & Sandberth, J. A. C. (1994). The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes. London: Academic Press.

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The Roles of Design Media for Teaching Architectural Design

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The Roles of Design Media

The Roles of Design Media for Teaching Architectural Design

Abstract: Mixed media design, which includes both pencil sketching and computer-aided design (CAD) modelling, and is frequently used in both the design industries and design schools. Research suggests that mixed media design environments provide several advantages over design environments that use singular media. Although a common outcome of CAD modelling is design documentation, researchers have argued that CAD modelling could support conceptual design. In our focused study four experts were invited to complete different architectural design tasks. They were asked to sketch first and then model their designs using CAD. A Function-Behaviour-Structure (FBS) coding scheme was adopted to analyse their cognitive actions, and the empirical evidence collected shows that being dissatisfied with sketches resulted in the entire CAD design phase becoming uncertain. Thus an optimal solution may not be achieved after the use of one design medium. This means that the following design sessions need to support designers to refine their prior designs by evaluating alternatives. The main contribution of this study is for teaching architectural design. A model was developed for the phenomenon of CAD modelling used to support conceptual design or design documentation in mixed media design environments.

Keywords: Architectural Design, Concept Design, Design Education, Design Media, Dissatisfaction, Uncertainty

INTRODUCTION

Contemporary design practice encompasses a range of visual representations including sketching, computer-aided design (CAD) modelling, manually sketched models and physical models. Designers use these media for multiple purposes, such as artifacts that reduce cognitive load, and as triggers that enable designers to communicate ideas and explore design problems (Tang and Gero, 2001). Previous research (Purcell and Gero, 1998; Tang and Gero, 2001) has investigated the roles of visual representations in enhancing designers' problem-solving processes. Romer, Pache, Weißhahn, Lindemann and Hacker (2001) found that the two most frequently used design media in both the design industry and design schools, were sketching and CAD modelling. Sketches are ambiguous but allow designers to explore alternatives, while CAD models accurately specify the dimensions of objects and their relationships with each other.

Due to the increased globalisation of architecture, engineering and construction (AEC) projects, current research has shifted from individual design environments to integrating different design environments to improve design outcomes (Goulding, *et al*., 2014). When Ibrahim and Rahimian (2010) compared traditional sketching, CAD modelling and mixed media to assess their influence on design cognition and activities, they found that mixed media design environments improved the quality of the design process as well as of the ultimate product design. Many researchers (French, 1985; Hales, 1993; Isaksen, *et al.*, 1994; Suwa and Tversky, 2001) have proposed different types of design research studies to improve the understanding of design activities. Even though a stereotypical outcome of CAD modelling is primarily documentation (Verstijnen, *et al.*, 1998; van Elsas and Vergeest, 1998), researchers have argued that CAD modelling could support conceptual design (Chen, 2007; Aish, 1986). Questions remain about what factors that change CAD modelling roles to supporting conceptual design in mixed media design environments. This paper builds on previous mixed media studies with an empirical exploration of sketching and CAD modelling in an architectural design processes. An initial critical review of relevant design works including the roles of different design media and design research studies is provided. In the next section, the design of the protocol analysis used for this study is described. Finally, our findings are presented.

DESIGN RESEARCH STUDIES

Mixed media design environments

In recent years, research has shifted from single design media to the influence of mixed media on cognitive activities during the conceptual design phase. Evidence for the use of mixed media comes from Sachse, Leinert and Hacker (2001) who surveyed more than 100 expert designers who used sketching prior to and concurrently with CAD modelling. Their study identified three positive outcomes of this approach: improved solutions, faster task completion, and fewer processing steps to develop CAD models. A similar result was found by Chen (2007) who studied design creativity when conventional and digital media were used simultaneously. Chen found that as designers move from sketching to digital tools, creativity is stimulated. This is because designers have opportunities to re-think previous ideas and to improve the quality of their designs. Ibrahim and Rahimian (2010) argued that the CAD software available at the time did not facilitate the intuitive aspects of conceptual design. Therefore, they introduced the concept of mixed media, in which sketching is used first, followed by CAD modelling. When mixed media were used, the overall design outcomes were superior to either CAD modelling or sketching.

Sketching plays a pivotal role in the initiation and development of creative ideas during the early design phase. Designers rely on it to support and focus their visual reasoning when exploring spatial relationships through diagrams. Different types of seeing ('seeing-as and seeing-that') stimulate the cognitive process of evaluation when designers re-interact with vague and ambiguous sketches Goldschmidt (1991). However, CAD modelling also has the potential to enhance design cognition and creativity (Hanna and Barber, 2001). It can be used to continually develop, iterate, and refine a form without having to delete a previous version. Therefore, it gives designers alternative and realistic ways to improve their designs (Madrzo, 1999). The use of CAD modelling during the early design process has several advantages: (1) It allows for faster generation of design alternatives; (2) It improves design communication in terms of design collaboration; and (3) It avoids costly errors (van Elsas and Vergeest, 1998).

Although researchers have argued that CAD modelling can support conceptual design by exploring design alternatives, the stereotypical outcomes of CAD modelling is primarily that of documentation (Verstijnen *et al*., 1998; van Elsas and Vergeest, 1998). It is clear that CAD modelling plays two roles in the conceptual design phase: exploration of design alternatives and the production of design documentation.

Reducing uncertainty through co-evolution

Providing solutions that effectively meet the requirements of a design brief is a designer's ultimate goal. A creative design process is best defined by its output – creative design processes produce great design outcomes (Sobek and Jain, 2004). Teaching students creative design processes is a common goal of many architectural design courses worldwide. Having a full understanding of the processes that lead to creative designs is of great interest to academics, designers as well as design researchers. In earlier descriptions of creative engineering design, Buhl (1960) described design as a linear sequence involving the following steps: (1) preparation, (2) analysis, (3) synthesis, (4) evaluation, and (5) presentation. Similarly, Isaksen et al. (1994) described creative approaches to a problem-solving activity as a linear sequence of: (1) framing a problem, (2) exploring data, (3) generating ideas, (4) developing solutions, and (5) appraising tasks.

The development of creative design processes is traditionally viewed as a sequence of activities involving the formulation of a problem, leading to the synthesis of solutions (Maher, Poon &

Boulanger, 1996). However, design problems are often ill-defined (Simon, 1983), meaning there is no definitive formulation of the design outcomes. Creative designers thus constantly generate design alternatives to redefine uncertainties. In practice, a designer develops and redefines both the formulation of a problem and his or her ideas for solutions, iterating between the design processes, the design requirements and the final outcomes.

An alternative model is Gero's Function-Behaviour-Structure (FBS) framework developed in 1990 (Gero, 1990) and evolved over the last two decades. The process represented by the FBS model (Figure 1) transforms design requirements into a design artifact. This model contains six design issues and eight design processes that describe all designed artifacts, irrespective of the specific design discipline.

Gero proposes the six design issues begin with the goal of designing being to transform a set of requirements (R) into a set of design descriptions (D). The function (F) of a designed object is defined as its purpose (or teleology). The behaviour (B) of that object is how it achieves its functions and is either derived (Bs) or expected (Be) from the structure. The structure (S) comprises the elements of an object and their relationships. A design description is never transformed directly from the function but undergoes a series of design processes related to the FBS design issues. These eight design processes include: a formulation (F→Be) which transforms functions into a set of expected behaviours; a synthesis (Be→S), wherein a structure is proposed that is likely to exhibit the expected behaviour; an analysis (S→Bs) of the structure which produces its derived behaviour; an evaluation process (Be⇆Bs) which acts between the expected behaviour and the behaviour derived from the structure; and documentation (S→D), which produces the design description (Gero & Kannengiesser, 2014). Depending on the structure, there are three types of reformulation, where new variables are introduced: reformulation of structure (S→S), reformulation of expected behaviour (S→Be), and reformulation of function (S →F). The primary advantage of the FBS coding scheme is that it clearly shows the relationships between the eight design processes and the six design issues. The FBS coding scheme has been used as a uniform framework to represent and classify design processes in numerous studies (Tang, *et al.*, 2011; Gero, *et al.*, 2012; Williams, *et al.*, 2013; Kan and Gero, 2009; Gero, *et al.*, 2011). Therefore, the FBS coding scheme is a proven approach that has been used adopted for this study.

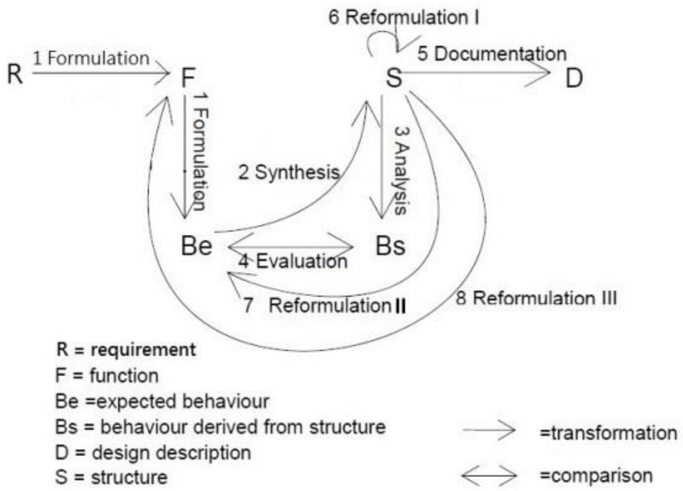


Figure 1. FBS design model (Gero and Kanengiesser, 2014)

Research in cognitive psychology has revealed that uncertainty is central to solving complex problems (Schunn and Trafton, 2012). Indeed, uncertainty is important in the earliest stage of problem solving because how a problem is initially discovered and structured is a vital precursor to problem solving (Paletz and Peng, 2009). Design tasks are concerned with ill-structured or wicked problems, where the solutions are unknown throughout the design process (Cross, 2009). Exploring different ideas under conditions of uncertainty is a natural occurrence (Beheshti, 1993). As a consequence, uncertainty becomes a means to help a designer explore design alternatives. Within the early design stage, a designer also engages with the iterative design process of evaluation to gain valuable insights into the boundaries of the original problem (Dorst and Cross, 2001).

In reality, many possible solutions are generated when designing to meet specific requirements. This process involves redefining problems and developing solutions called co-evolution by Maher and Poon (Maher and Poon, 1996) (Figure 2). This model fits Dorst and Cross's design creativity study (Dorst and Cross, 2001) in that they argue that creative design is not a matter of first defining a problem and then searching for a satisfactory solution. Creative design is a matter of the interchange of information between problem and solution spaces.

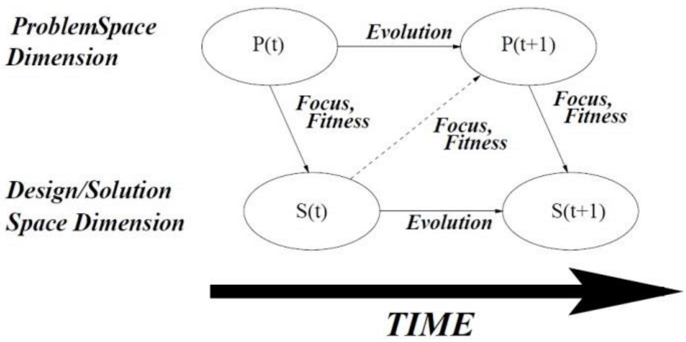


Figure 2. The co-evolution design model (Maher and Poon, 1996)

Gero and Kannengiesser (2014) also argued that there is no direct transformation from a problem to a solution. A designer needs to continually evaluate expected behaviours (Be) and behaviours derived from structures (Bs) until the structure performs its desired function. For instance, when a designer wants to design a structure to support a floor lamp, s/he will think of several possible solutions first (expected behavior, Be), design them (structure, S), and then iteratively test (behaviour derived from structure, Bs) whether or not to they achieve their goal (evaluation, Be⇆Bs). Uncertainty (problem space) and evaluation (co-evolution) form a unique relationship, which together with design alternatives (solution space) can be mapped onto the FBS model (Figure 3). Similarly, Tracey and Hutchinson (2016) argue that 'Uncertainty is central to design and designers seek to reduce it via problem-solution co-evolution' (p 91). Our research question is that what factors drive uncertainty when CAD modelling is used in mixed media design environments?

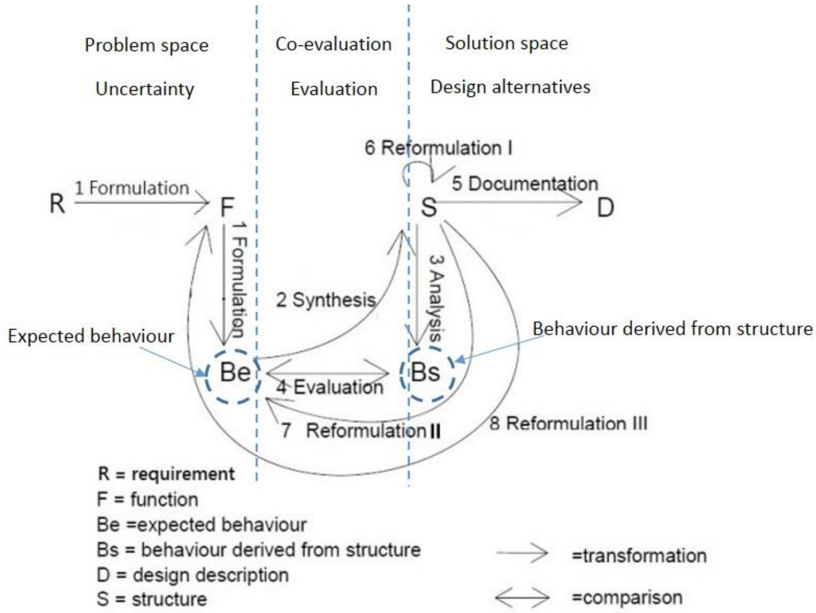


Figure 3. The mapping of uncertainty (problem space), evaluation (co-evolution) and design alternatives (solution space) into the FBS model (adopted from Gero and Kanengiesser, 2014)

METHODOLOGY

Protocol analysis

The credibility of a study depends upon the research method chosen and the way in which the research is conducted. Different approaches have been taken to study designers (Cross, 1999) including interviews with expert designers (Cross & Cross, 1995; Candy & Edmonds, 1996) observations and case studies (Gero & Sudweeks, 1998), simulation trials (Akin, 1993) and protocol studies (Rahimian, *et al.*, 2011; Candy, Bilda, *et al.*, 2004). The research question in this study is to determine the factors that lead to uncertainty when using CAD modelling in mixed media design environments.

Protocol analysis was selected as the most appropriate method because it offers a potentially effective technique for the controlled observation and experimental analysis of cognitive behaviour Akin, 1993; Suwa and Tversky, 1997). Protocol analysis can be used to help understand the design processes of designers, the knowledge they use, the cognitive actions they take and the strategies they employ. A typical application of protocol analysis is to ask designers how they design an artefact, however they usually find this question difficult to answer in detail. This is because designers retain their design thinking in their short-term memory while designing. Another possible method is to look at their sketches, notes or CAD models, but without further information it is difficult to understand their design processes. Many studies (Ibrahim and Rahimian, 2010; Rahimian, *et al.*, 2011; Candy, *et al*., 2004; Dorst and Dijkhuis, 1995) show that protocol analysis can record almost all information about designers' reasoning during the design process rather than simply relying on their design results for such insights.

There are two ways to report protocol data: retrospective and concurrent (think-aloud) verbalisation (Newell, 1990). Generally, retrospective verbalisation means that designers perform tasks and questioned afterwards about their thought processes during their design activities. Another approach is to video design sessions and to review recordings together with the designers, enabling them to interpret what happened. However, it may be difficult for designers to remember their thought processes after an activity is completed and the usefulness of this method is limited (Van Someren, *et al.*, 1994). Another problem with this approach is that designers may present their thought processes as more coherent and intelligent than they originally were; they may not report thoughts they actually had during the design process and may instead report false memories. This may give an erroneous impression of perfectly rational behaviour (Van Someren, *et al*., 1994). Designers' retrospection means that information must be retrieved from long-term memory and then verbalised. The disadvantage of this approach is that the retrieval process may not unearth all the information that was actually experienced in short-term memory during the design processes.

On the other hand, the think-aloud protocol requires designers to verbalise his / her thoughts while designing (Candy, *et al*., 2004; Gero and Tang, 2001). In other words, designers explain their thoughts whilst performing the task at hand. Unlike retrospective protocols for gathering verbal data, no set questions are asked. Designers are encouraged to give a concurrent account of their thoughts and to avoid interpreting what they are doing (Gero and Tang, 2001). This method is more successful because almost all of a designer's conscious effort is aimed at achieving the design task. This restricts the opportunities for them to reflect on their design activities. As such, the data gathered are very direct; there is no delay that can result in altered data. The advantages of concurrent verbalisation seem to meet the aim of this research because this process focuses on analysing designers' cognitive actions rather than using subjective reports.

Generally, protocol studies involve the following steps (Ibrahim and Rahimian, 2010; Dorst, 1996): (1) proposing a research direction or gap; (2) participant recruitment and experiment set-up; (3) conducting/recording the experiment; (4) transcribing protocol data; (5) developing of a coding scheme; (6) encoding the protocol data; (7) analysis of the protocol data; and (8) interpretation of results. It is important that design experiments are conducted with appropriate participants in term of their number, design experience and skills so that meaningful outcomes are obtained.

Development of the FBS coding structure for mixed media study

A coding scheme for a mixed media study was developed from the FBS design model to distinguish between the design activities that occur in sketching and in CAD modelling (Figure 4). Based on the FBS coding scheme, the sketching environment consists of six design issues (Rs, Fs, Bes, Bss, Ss, and Ds) while the CAD modelling environment also involves six design issues (Rc, Fc, Bec, Bsc, Sc and Dc). These separations enable different distributions of design issues to be collected and analysed.

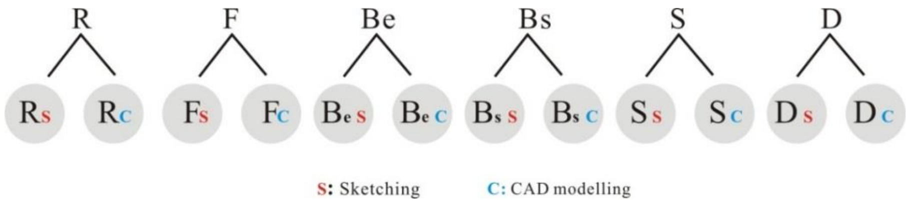


Figure 4. Development of the FBS design model for coding sketching and CAD modelling activities

Participant recruitment and mixed media experiment set-up

Protocol analysis can be used for a single designer, or a team of designers. Four architectural designers were recruited for this study. They were identified from those who satisfied the selection criteria. To be included, the participants needed: (1) a tertiary degree in architecture with a minimum of two-year of professional architectural practical experience; (2) competence in both sketching and CAD modelling; and (3) competence in practising and communicating design in English. Moreover, informed consents were obtained for experimentation with human subjects

Another challenge in experimental settings is the development of a design task suited to the research aims. Normally a 60 to 90-minute protocol task produces sufficient data and a manageable protocol size (Dorst, 1996). Dorst (1996) proposed that design tasks be challenging, realistic, appropriate, not too large, feasible in the time available and within the scope of knowledge of the researchers. Architectural designers often design buildings and this study provided a basic floor plan with its CAD model. Participants were asked at random to use this model to design a building for different purposes: an architectural office, a dream house and an art gallery (see Appendix). These tasks were appropriate because the task could be completed in approximately 75 minutes. Participants worked on the 2D layout by sketching, followed by CAD modelling (Figure 5).

Participant A Participant B

Participant C Participant D

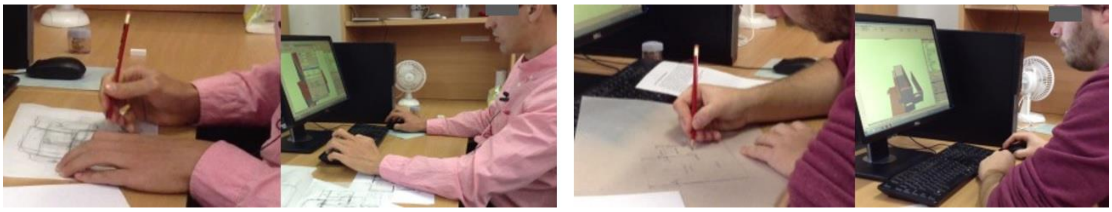


Figure 5. Participants used sketching followed by CAD modelling

RESULTS ANALYSIS AND DISCUSSION

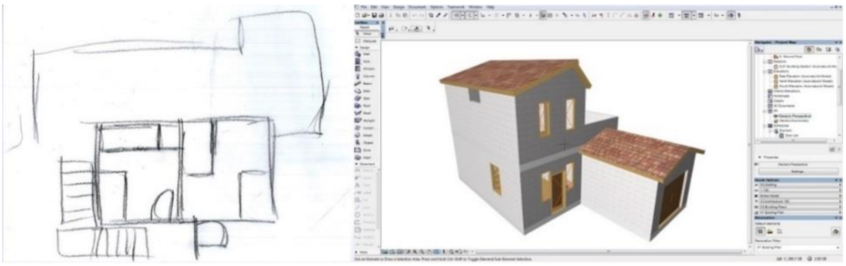
General design outcomes

Participants' verbal accounts of their sketching and CAD modelling design sessions were recorded on video and audio equipment. Subsequently, their verbal commentary was transcribed, segmented and coded. The segmentation and coding technique followed a principle of one segment with one code (one FBS design issue) (Gero, *et al.*, 2011). If a segment was identified as having more than one FBS design issues a further segment was needed. To improve the reliability of the protocol segmentation and coding results, the Delphi method was applied (Gero and McNeill, 1998). Linstone and Turoff (1975) suggest, 'Delphi may be characterized as a method for structuring a group communication process so that the process is effective allowing a group of individuals, as a whole, to deal with a complex problem' (p.3).

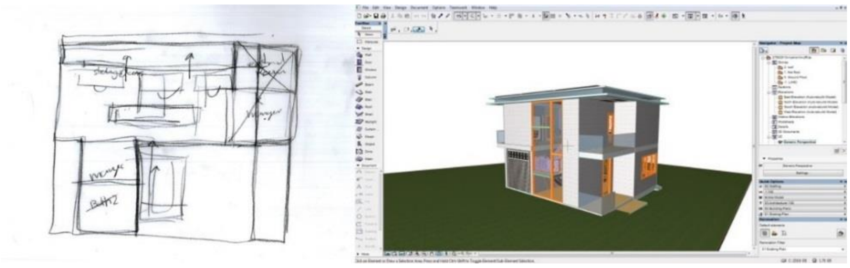
The crucial features of the Delphi method involve participants in four steps (Linstone and Turoff , 1975): (1) Exploring the issues and contributing additional information relevant to the issues; (2) Coming to an understanding of how the group views the issues; (3) Exploring significant disagreements (if any), to reveal the underlying reasons and to evaluate them; and (4) Evaluating all previously collected information. In Bilda et al.'s protocol studies (Bilda and Gero, 2007; Bilda, *et al.*, 2006), they adopted the Delphi method to verify the coding segments used for analysis. They coded the transcripts twice, allowing a one-month period between the two coding phases. The purpose of the interval was to avoid the researcher remembering how they previously coded segments. Resolving any differences in the two rounds of coding was a judgement call by the original researcher. Gero, Jiang and Williams claimed that utilising the Delphi method enabled inter-coder reliability of 85-95% to be reached (Gero, *et al.*, 2012). The percentage agreement between the individual rounds and the final arbitration was approximately 86%, which confirms the reliability of the coding results of this protocol study.

Because of this reliability rating, our study also adopted Bilda et al's approach. All participants completed and satisfied the design briefs (Figure 6), and their design activities were videoed, covering between 153 and 355 FBS design issues. Sketching design activities occupied between 56 and 89 FBS design issues and CAD modelling design activities occupied between 97 and 271 FBS design issues. The average number of cognitive efforts in CAD modelling is approximately 2.5 times than of sketching. This indicates that the CAD design phase required more cognitive effort, resulting in more FBS coding than the sketching session. Due to the varied quantities of each participant's segmentations in sketching and CAD modelling, the occurrences of design issues and design processes were normalised as percentages (%) of the total issues and processes, as described in the following sections.

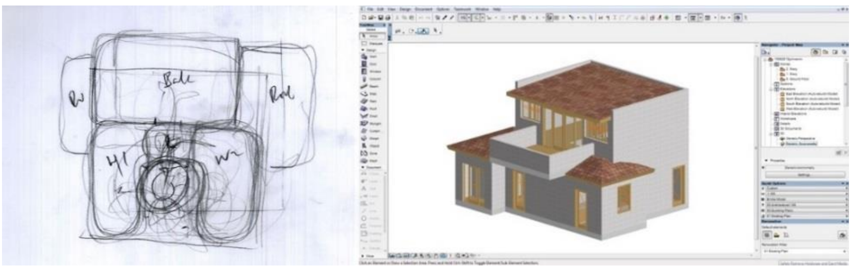
Participant A: Architectural Office Design



Participant B: Architectural Office Design



Participant C: Art Gallery Design



Participant D: Dream House Design

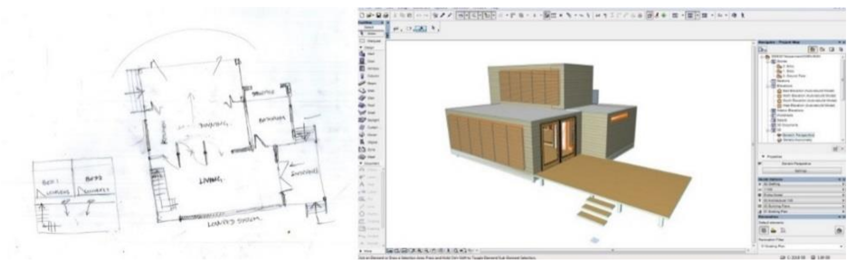


Figure 6. Participants' design outcomes from sketching and CAD modelling

Distributions of design issues and design processes in mixed media design environments

Results from the study indicate that the four participants shared a similar distribution of design issues (Figure 7). The majority of cognitive effort was expended reasoning about the structure and the behaviour derived from the structure (Bs) (>20%). The design issue of requirement (R) had the lowest cognitive focus (<6%). Noticeable differences were observed among the participants on the issues of requirement (R) (5% difference between participant A and D), function (F) (8.6% difference between participant A and D), expected behaviour (Be) (6.2% difference between participant B and C), behaviour derived from structure (Bs) (16.3% difference between participant C and D), structure (S) (18.8% difference between participant B and C) and description (D) (6.7% difference between participant C and D). Participant C's design behaviour differed to others in terms of the (Be), (Bs), (S) and (D).

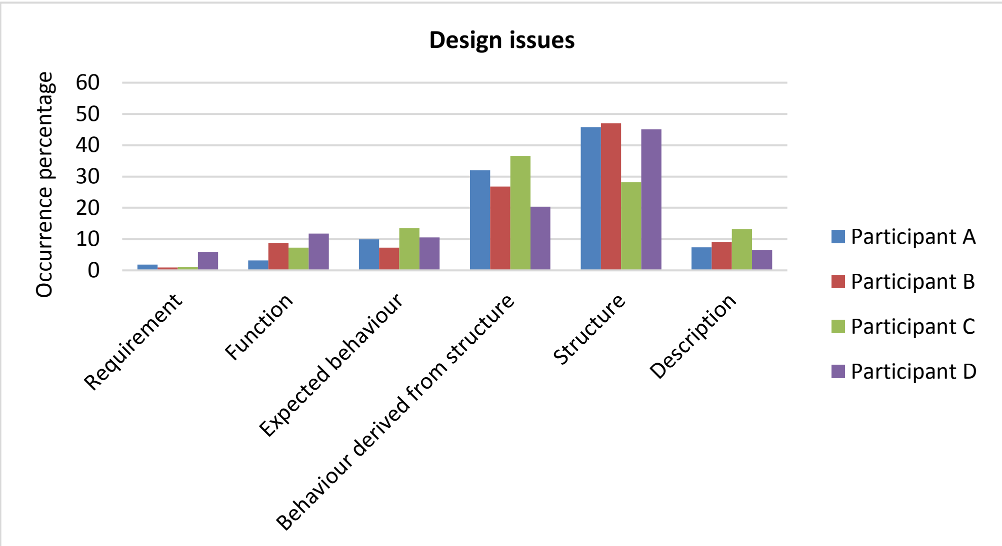


Figure 7. Participants' FBS distributions of design issues in mixed media design environments

A syntactic design process is one that presumes all segments are cognitively related to their immediate preceding segment. They are design processes which transform from one segment to the other (Williams, *et al.*, 2013). In this study, participants shared a similar design process distribution (Figure 8). The majority of time spent was in the design process Reformulation I. However, participant C spent the most time on evaluation. The following sections analyse participants' FBS distributions in terms of design issues and design processes in CAD modelling to understand the roles of CAD modelling in mixed media design environments.

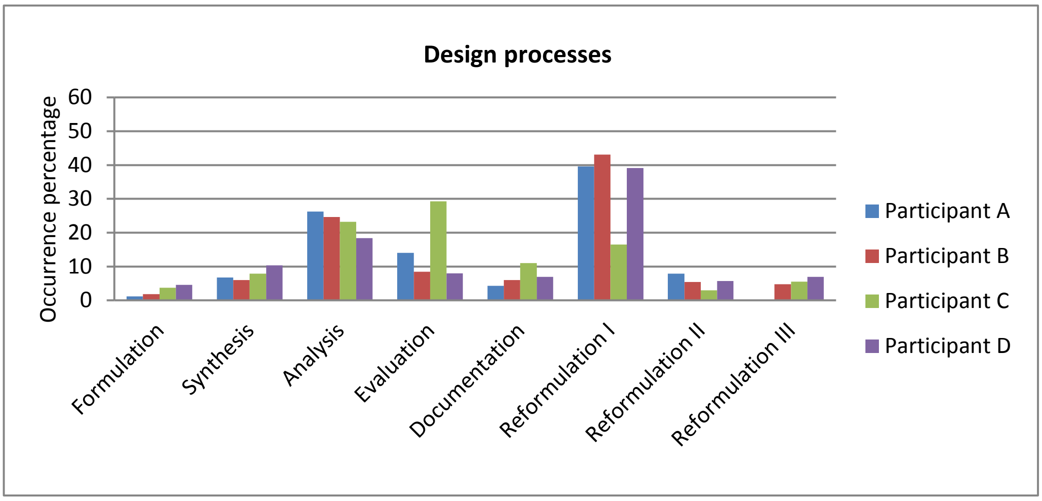


Figure 8. Participants' FBS distributions of design processes in mixed media design environments

Distributions of design issues and design processes in CAD modelling

We established that design activities in sketching and CAD modelling can be coded differently using the coding structure developed for this study (Figure 4). While (Rs) refers to sketching and (Rc) refers to CAD modelling, other examples of coding segments for sketching and CAD modelling are shown in Table 2:

Table 2. Examples of coding segments for sketching and CAD modelling

Number	Utterance	Code by environments
58	Say about 600, five and two meters for each of those.	Ss
59	and the smoking area out of just the roof terrace	Ss
60	Just going to review afterward make sure I think everything is going to work when it's drawn to scale.	Bes
61	I think that looks okay.	Bss
133	2600. That's …	Sc
134	See how it works in 3D.	Dc
135	It's not accurate but it works.	Bsc
136	I was going to get rid of it anyway, so, lose that.	Dc

In the CAD modelling design environment, it was observed that participants expended the majority of their cognitive effort considering design issues related to structure (approximately 30~52%) and behaviour derived from structure (23~38%) (Figure 9), as well as design processes of reformulation I (19~47%) and analysis (21~33%) (Figure 10). This suggests that most participants focused mainly on modelling the solution structures of their final designs. However, only participant C spent the majority of his cognitive effort on the design process of evaluation (30%) which concerned expected behaviour (Be) and behaviour derived from structure (Bs). This indicates that participant C's reasoning processes were different to other participants in CAD modelling (Figure 10). The next section applies Markov chains to analyse the events that follow (Be) and (Bs).

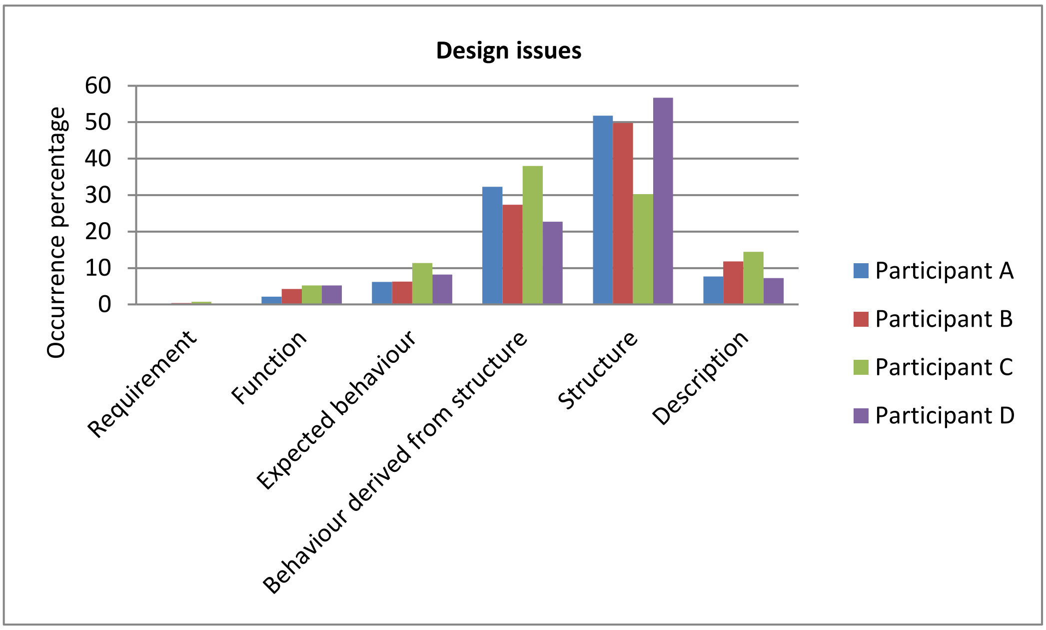


Figure 9. Participants' FBS distributions of design issues in CAD modelling

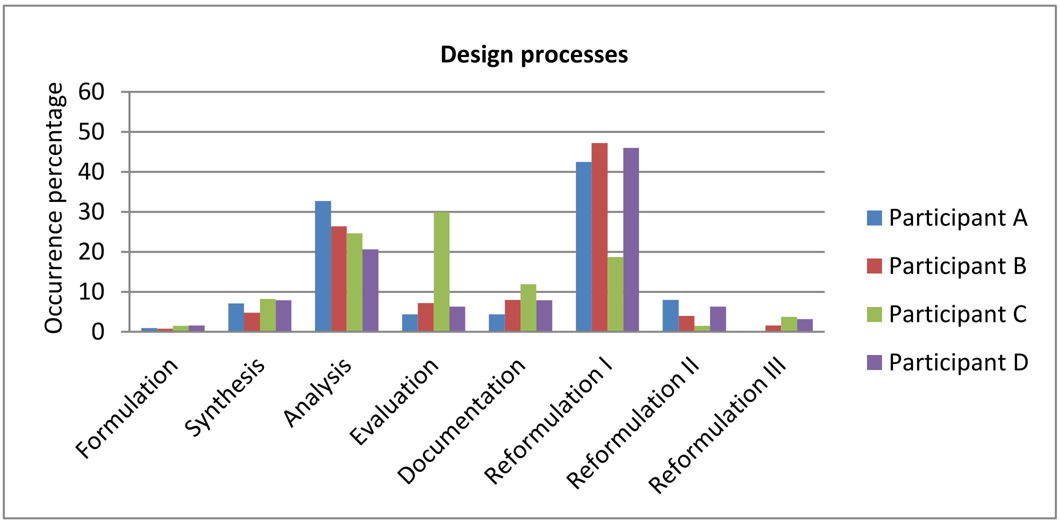


Figure 10. Participants' FBS distributions of design processes in CAD modelling

Using Markov chains to describe the FBS transition in CAD modelling

The above analyses of FBS distributions found that participant C's distributions differed to those of others in the CAD design phase. Traditional protocol analysis often assumes that each segment is an independent event, while Markov chains examine the sequence of events describing the probability of one event leading to another (Kan and Gero, 2009). McNeill, Gero and Warren's protocol study (1998) found that the most likely event after analysis is an evaluation event. According to Kan and Gero's protocol study (2009), each segment code can be viewed as one design event, one design move or one unit. Markov chains not only summarise the transitions between the FBS design events (Table 3-6) but also describe the probability of one design event leading to another. These can be viewed as behavioural patterns using the linkoder software developed by Gero, Kan and Pourmohamadi (2011). As mentioned in the section of reducing uncertainty through co-evolution, the iterative processes of evaluation between problem and solution spaces has the potential to turn routine design processes into creative ones. By understanding evaluation as a bridge linking uncertainty to design alternatives, it is a two directional process: (Be→Bs) and (Bs→Be). Participants' probable future design events after the (Be) and the (Bs) were illustrated and compared (Table 3-6). If the current event is (Be), the probable future event of participant C will be the (Bs) (evaluation, 0.55); whereas another probable future event will be synthesis (Be→S). From the probable future event after the (Bs), participant C also will have the highest probability (0.23) among others: participant D (0.1), participant B (0.08) and participant A (0.03). This means that participant D, B and A mainly focused on documenting their designs from sketches in the CAD design phase. Participant C was more concerned about design problems and solutions and evaluated them through the CAD design phase. The next section uses dynamic models to visualise the design processes involved in CAD modelling.

Table 3. Markov chains for participant A

Participant-A			Syntactic			
	R	F	Be	Bs	S	D
R						
F	0.00	0.00	0.25	0.25	0.50	0.00
Be	0.00	0.00	0.00	0.25	0.67	0.08
Bs	0.00	0.03	0.03	0.16	0.64	0.13
S	0.00	0.00	0.09	0.37	0.48	0.05
D	0.00	0.07	0.00	0.80	0.13	0.00

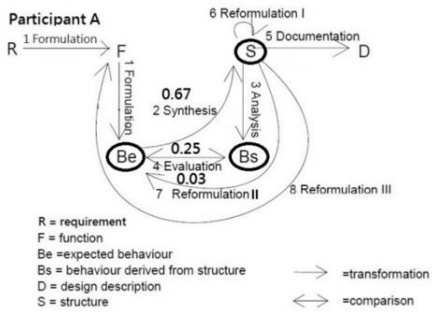


Table 3 shows that the probable future event of participant A after (Be) is (S) (synthesis, 0.67) and the iterative design process of evaluation is 0.28 (0.25 plus 0.03).

Table 4. Markov chains for participant B

Participant-B		Syntactic			
	R	F	Be	Bs	S	D
R	0.00	0.00	0.00	0.00	1.00	0.00
F	0.00	0.00	0.10	0.10	0.70	0.10
Be	0.00	0.08	0.08	0.31	0.46	0.08
Bs	0.00	0.08	0.08	0.22	0.45	0.17
S	0.00	0.02	0.05	0.30	0.54	0.09
D	0.00	0.07	0.07	0.21	0.46	0.18

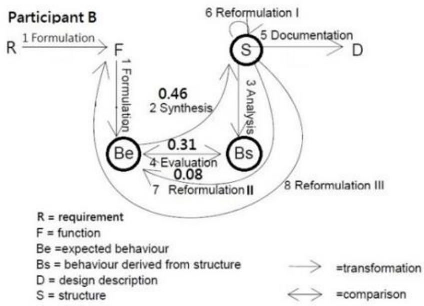


Table 4 shows that the probable future event of participant B after (Be) is (S) (synthesis, 0.46) and the iterative design process of evaluation is 0.39 (0.31 plus 0.08).

Table 5. Markov chains for participant C

Participant C		Syntactic				
	R	F	Be	Bs	S	D
R	0.00	0.00	0.00	1.00	0.00	0.00
F	0.00	0.18	0.18	0.55	0.09	0.00
Be	0.00	0.03	0.00	0.55	0.35	0.06
Bs	0.01	0.06	0.23	0.26	0.32	0.12
S	0.00	0.06	0.02	0.41	0.31	0.20
D	0.00	0.00	0.08	0.45	0.26	0.21

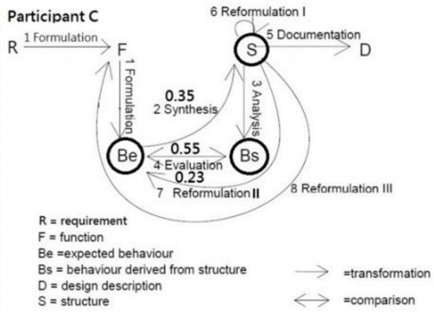


Table 5 shows that the probable future event of participant B after (Be) is (Bs) (evaluation, 0.55) and the iterative design process of evaluation is 0.78 (0.55 plus 0.23).

Table 6. Markov chains for participant D

Participant-D		Syntactic				
	R	F	Be	Bs	S	D
R						
F	0.00	0.20	0.20	0.20	0.20	0.20
Be	0.00	0.00	0.00	0.29	0.71	0.00
Bs	0.00	0.05	0.10	0.20	0.60	0.05
S	0.00	0.04	0.08	0.25	0.55	0.09
D	0.00	0.00	0.00	0.14	0.86	0.00

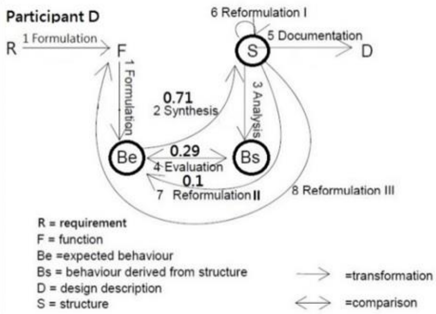


Table 6 shows that the probable future event of participant B after (Be) is (S) (synthesis, 0.71) and the iterative design process of evaluation is 0.39 (0.29 plus 0.1).

Dynamic models to visualise the design processes in CAD modelling

Figure 11 and 12 show the dynamic models of participant B and C during the CAD design process.

Dynamic models using the linkoder software (Gero, *et al*., 2011) make it possible to visually describe design moves using different colours. Fig. 11 shows that participant B produced 256 segments in the CAD design process and that these clearly focused on reformulation I (light blue, S→S) and analysis (yellow, S→Bs). The two peaks are caused by reformulation I and analysis around segments 26 and 100. This shows that participant B mainly focused on structure-related issues such as object dimensions and material selections in CAD modelling.

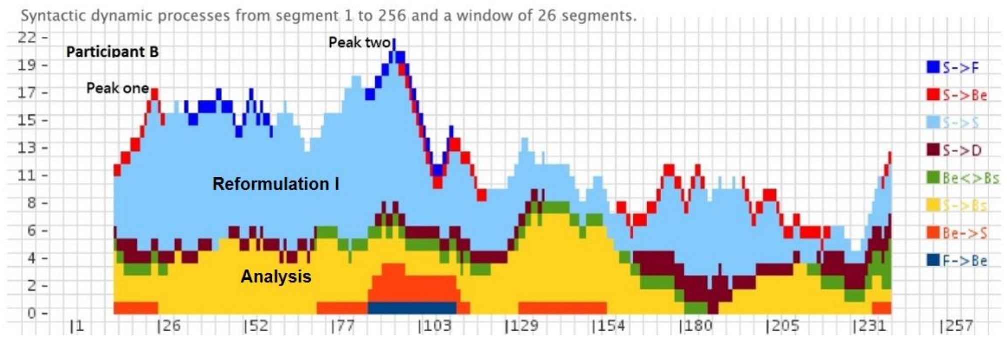


Figure 11. Participant B, dynamic model of CAD process

Figure 12 shows that participant C produced 280 segments and spent the majority of his reasoning on the design processes of evaluation (green, Be→Bs) and analysis (yellow, S→Bs). The two peaks result from evaluation, analysis and reformulation I around segment 84 and 230. This reveals that participant C mainly focused on the design process of evaluation between problem and solution spaces.

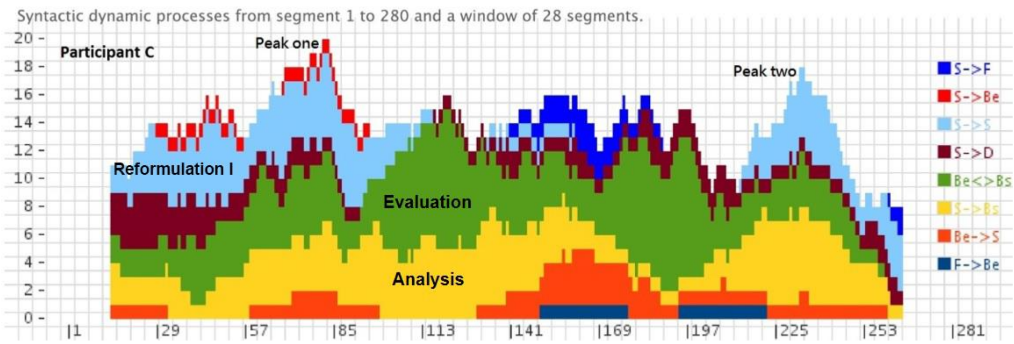


Figure 12. Participant C, dynamic model of CAD process

Uncovering uncertainty through dissatisfaction with sketches

To explore the factors that changed the roles of CAD modelling in mixed media design environments, it was informative to look at the participants' design protocols of segmentations at the end of the sketching sessions. A review of every segment indicated that participants A, B, and D were satisfied with their sketches. Only participant C was dissatisfied with his sketches so his CAD modelling design phase remained uncertain (Figure 13). Although the majority of his effort was devoted to evaluating his design alternatives, participant C was nevertheless dissatisfied with his sketching, stating:

‘Okay, so I'm done with the drawings, I think. I don't like it. I like going back to the drawing, so - but I understand the exercise, so now I'm going to try, from what I have drawn - from what I have drawn which is very rough, to make it work on the model, which should be easy enough.’

However, participant C was dissatisfied with his sketches, but tried to build a CAD model based on his rough sketches, and thought this would be easy. This illustrates Participant C’s uncertainty which turned the CAD design phase into a creative design process. Based on our protocol analysis in terms of the FBS distributions, Markov chains and dynamic models empirically support Tracey and Hutchinson’s argument: When uncertainty arises during a design task, producing new solutions to a problem involves a process in which missing information is recovered from the design alternatives. This phase involves the iterative process of evaluation to reduce uncertainty (Tracey and Hutchinson, 2016). Although the findings were generalised by the small sample size, the empirical evidence makes sense answering the reason of role changes in CAD design processes.

Figure 13. Participant C was dissatisfied with his sketches

Participants’ comments

Participants provided comments on completion of their experiments. These (below) pointed to a single solution which is integrating sketching into the CAD modelling design process.

‘By restricting the process to the sketching as design and then CAD as documentation only and no allowance to switch between them the capacity of each form is limited. Some design will always happen in the CAD environment, and some documentation (even if only for the designers’ own records) will happen best with pencil and paper, so assuming that the division is clear and discreet is wrong. It is generally not possible to memorize a design and then CAD it up correctly, so referring to the sketch is vital’ (Participant A).

'Without being able to switch it took too long to try different design combinations if the first design didn't fit within the building properly. Then I was left to try to design straight into CAD which is much less intuitive then sketching' (Participant D).

'I personally found the design process more difficult as once I had sketched my ideas and then placed them in CAD I could not sketch further ideas. The problem of this approach is the practitioner need to 'fix' encountered problems on the screen and not draw by hand possible alternative solutions. This process is much slower then returning to the 'thinking hand' for developing new ideas' (Participant B).

After reviewing participants' design segments, participant A mentioned that he wanted to use sketching during the CAD modelling process when sketches and CAD models did not match each other (Table 7). Whatever the mechanism, the assumption is that uncertainty with current designs stimulates new solutions to solve problems using different design environments.

Table 7. Participant A's design protocol during CAD modelling

No.	**Utterance**	**Code**
177	'I hope that would be a solution enough. Well … okay. Let's think about reconfiguring our reception area. If we had a bathroom on the outside of this building … that won't work.'	Bsc
178	'Okay this is the point in time when I want to take out a pencil and start sketching again.'	Dc
179	'The reception desk … a little there some chairs that are not working here.'	Bsc

Lastly, from empirical evidence, we confirmed that dissatisfaction with prior sketches resulted in CAD modelling being used to support conceptual design. Being dissatisfied with sketches, the whole CAD design phase became uncertain. This played a key role driving designers to new solutions and involving considerable cognitive effort on evaluation. This also fits Christensen and Schunn's (2009) study because higher uncertainty occurred at the beginning of the design process (e.g. here is sketching). Once designers satisfied their sketch outcomes, the following CAD design phase was mainly for documentation because uncertainty became lower. This phenomenon is illustrated below (Figure 14):

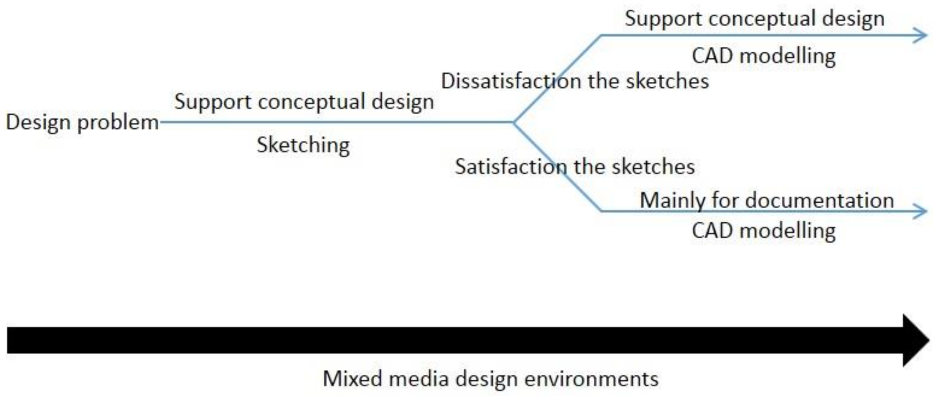


Figure 14. A diagram showing how CAD modelling is used differently in mixed media design environments.

CONCLUSION AND FUTURE STUDIES

This paper has examined the effect of different design media in the conceptual design phase, i.e. sketching and CAD modelling. Although they support conceptual design, the normal understanding of CAD modelling is that it is mainly used for documentation. In addition, most research in this area is based on single design media to explore designers' cognitive reasoning processes. However, solving a design task using a single design medium does not address the increasing complexity of design problems. As a result, we propose an approach where CAD modelling is gradually integrated with sketching in mixed media design environments.

To understand the relationship between uncertainty and evaluation, different creative design models were critically reviewed. Complicated and ill-defined design problems make the design process uncertain. This uncertainty drives designers to explore other design alternatives. To produce the best solution for the design problem, the design process involves co-evolution between problem and solution spaces to reduce uncertainty. The design process of evaluation is iterative (not sequential) so the FBS design model was applied. The relationships between different creative processes map to the FBS design model and this mapping has been provided above.

We found that designers' cognitive actions occurred in sketching and CAD modelling and may be defined using the FBS coding structure. The justifications for applying protocol analysis, the think aloud protocol and the FBS coding scheme were also provided. Our results show that designers produce 2.5 times more FBS segments in CAD modelling than in sketching. This means that the designers spent the majority of their reasoning effort during the CAD modelling session which had a significant influence on the overall FBS design issues and process distributions.

We conducted protocol analyses with four expert designers. We explored how they interacted with mixed media, and focused on the use of CAD in the design phase. Participant A, B and D spent the majority of their cognitive effort on the design process of reformulation I ($S \rightarrow S$). This suggests that they were using CAD modelling for documentation because many segments were coded according to the design issue of structure (S) for building components or selecting materials. However, participant C spent the majority of his cognitive effort on the design process of evaluation (Be⇆Bs). This suggests that he was using CAD modelling to support conceptual design because it refers to co-evolution for reducing uncertainty. The Markov chains and dynamic model analyses also provided empirical evidence of this.

A crucial point was reached when designers wanted to shift from sketching to CAD modelling. The contents of the design protocols that occurred at the end of the sketching sessions were examined to identify the factors that triggered this change. One factor was dissatisfaction with the sketches and this turned the CAD design phases into a creative design process. This occurred because dissatisfaction increased the degree of uncertainty at the beginning of the CAD modelling sessions.

The main contribution of this study is for teaching architectural design. Due to the increased complexity of design tasks, different technical design media are used to facilitate design processes. However, each design medium has its advantages and disadvantages. Thus an optimal solution may not be achieved after the use of one design medium. This means that the following design sessions (e.g. CAD modelling) need to support designers to refine their prior designs (e.g. in sketching session) by evaluating alternatives.

One of the limitations of protocol research is the time required for both data collection and analysis (Salman, 2011). It proved difficult to recruit participants who were competent in both sketching and CAD modelling, and who were interested in conceptual architectural design tasks. However, a sample size from one to three is acceptable in most protocol design studies (Jiang & Yen, 2009). In addition, the experimental set-ups were carefully considered and the approach of using mixed media was based on previous mixed media studies. These statements confirm the validity of this study.

Based on these comments further research is warranted where participants are free to switch between sketching and CAD modelling. ‘I found this method difficult as it does not suite my natural design behaviour. I felt restricted to the CAD tools available to me, only using them for documentation’ (Participant A). This quote suggests that alternative experimental set-ups that explore changes of designers’ behaviours by switching between sketching and CAD modelling may extend this research area.

REFERENCES

Aish, R. (1986). Three-dimensional input and visualization, Computer-Aided Architectural Design Futures, CAAD Futures Conference Proceedings 68-84.

Akin, O. (1993). Architects' reasoning with structures and functions, environment and planning B: Planning and Design, 20, 273-294.

Beheshti, R. (1993). Design decisions and uncertainty. Design Studies, 14 (1) 85-95.

Bilda, Z. & Gero, J. S. (2007). The impact of working memoery limitations on the design process during conceptualization. Design Studies, 28, 343-367.

Bilda, Z., Gero, J. S. & Purcell, T. (2006). To sketch or not to sketch? That is the question. Design Studies, 27(5) 587-613.

Buhl, H. (1960). Creative engineering design. Iowa State University, Iowa.

Candy, Z. Bilda, Z., Maher, M. L. & Gero, J. S. (2004). Evaluating software support for video data capture and analysis in collaborative design studies, Proceedings of QualIT04 (Qualitative Research in IT and IT in Qualitative Research) Conference, Brisbane, Australia.

Candy, L. & Edmonds, E. (1996). Creative design of the Lotus bicycle. Design Studies, 17(1) 71-90.

Chen, Z. R. (2007). How to improve creativity: Can designers improve their design creativity by using conventional and digital media simultaneously? CAAD Futures 2007, Proceedings of the 12th International CAAD Futures Conference 571-583.

Cross, N. (2001). Achieving pleasure from purpose: The methods of Kenneth Grange, Product Designer. Design Journal, 4(1) 48-58.

Cross, N. (1999). Natural Intelligence in Design, Design Studies, 20 25-29.

Cross, N. & Cross, A. (1995). Observations of teamwork and social processes in design. Design Studies, 16(2) 143-170.

Christensen, B. T. & Schunn, C. D. (2009). The role and impact of mental simulation in design. Applied Cognitive Psychology, 23 327-344.

Dorst, K. & Cross, N. (2001). Creativity in the design process: Co-evolution of problem–solution. Design Studies, 22(5) 425–437.

Dorst, K. & Dijkhuis, J. (1995). Comparing paradigms for describing design activity. Design Studies, 16(2) 261-275.

Dorst, K. (1996). The design problem and its structure, in N. Cross, H. Christianns and K. Dorst (eds.), Analysing Design Activity, Chichester and New York: John Wiley, 17-35.

van Elsas P. A. & Vergeest, J. S. M. (1998). New functionality for computer aided conceptual design: the displacement feature. Design Studies, 19 (1) 81–102.

French, M. (1985). Conceptual design for engineers. The Design Council, London.

Gero, J. S. (1990). Design prototypes: A knowledge representation schema for design. AI Magazine, 11(4) 26-36.

Gero, J. S. & Kannengiesser, U. (2014). The Function-Behaviour-Structure ontology of design, in Amaresh Chakrabarti and Lucienne Blessing (eds), An Anthology of Theories and Models of Design, Springer, pp. 263-283.

Gero, J. S. & McNeill, T. (1998) An approach to the analysis of design protocols, Design Studies 19(1) 21-61.

Gero, J. S., Jiang, H. & Williams, C. B. (2012). Does using different concept generation techniques change the design cognition of design students? ASME IDETC DETC2012-71165.

Gero, J. S., Kan, J. W. T. & Pourmohamadi, M. (2011). Analysing design protocols: Development of methods and tools. In International Conference on Research into Design, Indian Institute of Science Bangalore, India.

Gero, J. S. & Sudweeks, F. (1998). Artificial Intelligence in Design ’98, Dordrecht: Kluwer.

Gero, J. S. & Tang, H. H. (2001). The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of design protocols. Design Studies, 19(1) 21-61.

Goldschmidt, G. (1991). The dialectics of sketching, Creativity Research Journal, 4(2) 123–143.

Goulding, J. S., Rahimian, F. P. & Wang, X. (2014). Virtual reality-based cloud BIM platform for integrated AEC projects. Journal of Information Technology in Construction (ITCON), 19 (Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends) 308-325.

Hales, C. (1993). Managing engineering design. Longman Scientific and Technical, England, Harlow.

Hanna, R. & Barber, T. (2001). An inquiry into computer in design: Attitudes before - attitudes after, Design Studies, 22, 255-281.

Ibrahim, R. & Rahimian, F. P. (2010). Comparison of CAD and manual sketching tools for teaching architectural design. Automation in Construction, 19(8) 978-987.

Isaksen, S. G., Dorval, K. B. & Treffinger, D. J. (1994). Creative approaches to problem solving. Kendall Hunt Publishing Co., Dubuque, Iowa.

Jiang, H. & Yen, C. (2009). Protocol analysis in design research: A review. In the International Association of Societies of Design Research (IASDR) 2009 Conference 147-157.

Kan, J. W. T. & Gero, J. S. (2009). A generic tool to study human design activity, in R Noell Bergendahl, M, Grimheden, M, Leifer, L, Skogstad, P and Badke-Schaub, P (eds), Human Behavior in Design, Design Society 123-134.

Kan, J. W. T. & Gero, J. S. (2005). Can entropy indicate the richness of idea generation in team designing? Proceedings of the 10th International Conference on Computer Aided Architectural Design Research in Asia (CAADRIA 2005), New Delhi, India.

Linstone, H. A. & Turoff, M. (1975). The Delphi Method; Techniques and Applications, Addison-Wesley, Reading Massachusetts.

Madrzo, L. (1999). Types and instances: A paradigm for teaching design with computers, Design Studies, 20(2) 177-194.

Maher, M. L. Poon, J. & Boulanger, S. (1996). Formalizing design exploration as co-evolution: A combine general approach. In J. S. Gero & F. Sudweeks (Ed.), Advances in Formal Design Method for CAD. London, England.

Maher, M. L. & Poon, J. (1996). Modelling design exploration as co-evolution. Microcomputers in Civil Engineering. 11(3), 195-209.

McNeill, T., Gero, J. S. & Warren, J. (1998). Understanding conceptual electronic design using protocol analysis, Research in Engineering Design 10(3) 129-140.

Newell, A. (1990). Unified theories of cognition. Cambridge, Mass: Harvard University Press.

Paletz, S. B. F. & Peng, K. (2009). Problem finding and contradiction: Examining the relationship between naïve dialectical thinking, Ethnicity, and Creativity. Creativity Research Journal, 21, 139-151.

Purcell, T. & Gero, J. S. (1998). Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology, Design Studies 19(4) 389-430.

Rahimian, F. P., Ibrahim, R., Rahmat, R. W. B. O. K., Abdullah, M. T. B. & Jaafar, M. S. B. H. (2011). Mediating cognitive transformation with VR 3D sketching during conceptual architectural design process. Archnet-IJAR, International Journal of Architectural Research, 5(1) 99-113.

Romer, A., Pache, M., Weißhahn, G., Lindemann, U. & Hacker, W. (2001). Effort-saving product representations in design-results of a questionnaire survey. Design Studies, 22(6) 473-491.

Sachse, P. Leinert, S. & Hacker, W. (2001). Designing with computer and sketches, Swiss Journal of Psychology, 60(2) 65-72.

Salman, H. (2011). The impact of CAAD on design methodology and visual thinking in architectural education. (PhD thesis) Robert Gordon University.

Schunn, C. D. & Trafton, J. G. (2012). The psychology of uncertainty in scientific data analysis. In G. Feist and M. Gorman (Eds.), Handbook of the Psychology of Science. New York, NY: Springer Publishing, pp. 461-483.

Simon, H. A. (1983). Search and reasoning in problem solving, Artificial Intelligence, 21. 7-29.

Sobek II, D. K. & Jain, V. K. (2004). Two instruments for assessing design outcomes of capstone projects, Proceeding of the 2004 American Society for Engineering Education Conference and Exposition.

Suwa, M. & Tversky, B. (2001). How do designers shift their focus of attention in their own sketches? In Anderson, M., Meyer, B. and Olivier, P. (eds.) Diagrammatic Reasoning and Representation, Berlin: Springer 241-260.

Suwa, M. & Tversky, B. (1997). What do architects and students perceive in their design sketches? A protocol analysis, Design Studies, 18(4) 385-403.

Tang, H. H. & Gero, J. S. (2001). Cognition-based CAAD, in B de Vries, J van Leeuwen and H Achten (eds), CAADFutures 2001, Kluwer, Dordrecht 523-531.

Tang, H. H. & Gero, J. S. (2001). Sketches as affordances of meanings in the design process, in JS Gero, B Tversky and T Purcell (eds), Visual and spatial reasoning in Design II, Key centre of design computing and cognition, University of Sydney, Sydney 271-282.

Tang, H. H. Lee, Y. Y. & Gero, J. S. (2011). Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the Function-Behaviour-Structure coding scheme. Design Studies, 32(1) 1-29.

Tracey, M. W. & Hutchinson, A. (2016). Uncertainty, reflection, and designer identify development. Design Studies, 42 86-109.

Van Someren, M. W., Barnard, Y. F. & Sandberth, J. A. C. (1994). The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes. London: Academic Press.

Verstijnen, I. M. Hennessey, J. M. Leeuwen, C. van Hamel, R. & Goldschmidt, G. (1998). Sketching and creative discovery. Design Studies, 19 (4) 519–546.

Williams, C. B., Lee, Y., Gero, J. S. & Paretti, M. (2013). Exploring the effect of the design prompt on students' design cognition, ASME IDETC2013 DETC2013.

Appendix: design briefs, 2D layout and CAD modelling

Design Brief: ***A Two-floor Art Gallery Design***

You are required to design a one-floor house into a two-floor art gallery. The gallery is for two salespeople with one manager and will focus on the customers' interaction with the space and its overall aesthetic appeal. The art gallery design must use the provided conversion task but CAD modelling such as walls, doors, etc., can be modified, added or deleted. The gallery should include a reception, big show room, kitchen, bathroom, storage room, hallway, stairs from ground-level and two working rooms with a big balcony on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style, with colour or material; but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models and within the 1-1.5hour timeline.

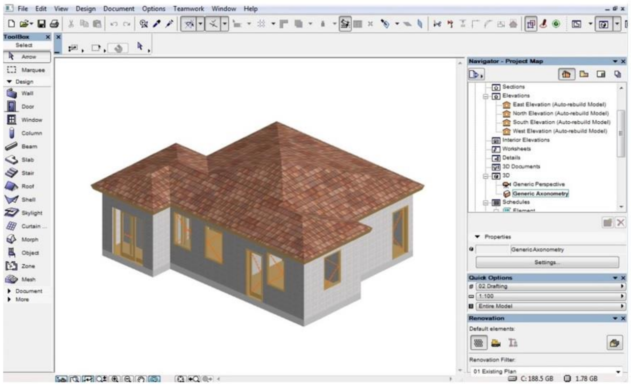
Design Brief: ***A Two-floor Architectural Office Design***

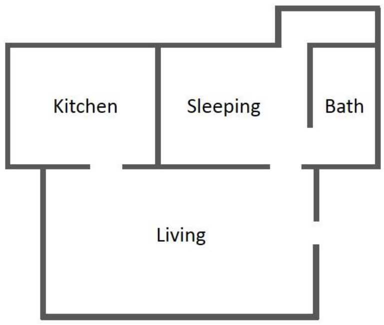
You are required to design a one-floor house into a two-floor architectural office for three architects and one manager. It will need to focus on the architectural designers' interaction with the space and its overall aesthetic appeal. The office design must use the conversion task provided but CAD modelling such as walls, doors, etc., can be modified, added or deleted. This office should include a reception area, meeting room, kitchen, bathroom, garage, hallway, stairs from ground-level and two design rooms, with an open smoking area on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style with colour or material but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models.

Design Brief: ***A Two-floor Dream House Design***

You are required to design a one-floor house into a two-floor dream house. The apartment is for a young family with one child and will focus on the users' interaction with the space and its overall aesthetic appeal. The apartment design must use the provided extension task but CAD modelling such as walls, doors, etc., can be modified, added or deleted, because the current layout does not satisfy them – for example, the female owner wants more space for the bathroom. This apartment should include a living room, kitchen, bathroom, stairs on at ground-level and two bedrooms with balconies on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style with colour or material but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models.

The experimental CAD model with its 2D layout





Autobiographical Sketches

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Using Suitable Design Media Appropriately: Understanding How Designers Interact with Sketching and CAD Modelling in Design Processes

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Abstract: This paper investigates the roles of sketching and computer-aid-design modelling in mixed media design environments, and how switching behaviours could impact on them. Six designers participated in a protocol study in which their activities were video recorded. The recordings were coded using the Function-Behaviour-Structure coding scheme. Having completed their tasks, participants reviewed the recordings and were asked to explain their switching behaviours. A three-level coding scheme for analysing switching behaviours was adapted from relevant literature. The results show that both sketching and CAD modelling played a markedly similar role in the design process because the design media selected suited the designers' needs. Moreover, our proposed three types of switching behaviours supported designers in perception, media and concept levels during designing.

Keywords: design processes, computer aided design, protocol analysis, switching behaviour, mixed media design environments

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External aids such as sketches and computer aided design (CAD) models are extremely influential cognitive activities during the early stage of conceptual design. They are used to build design environments that support the exploration of ideas and visual representations (Oxman, 2006). They also encourage the identification of detailed problems while simultaneously enhancing designers' cognitive activities (Goldschmidt & Smolkov, 2006). Extensive research into a range of traditional and digital design environments has provided valuable information on the most frequently used design media (Goldschmidt, 1994; Kavakli & Gero, 2001; Purcell & Gero, 1998).

It is challenging to achieve a design goal without sketching. Sketching does more than communicate ideas; it assists in visualising, conceptualising and understanding the forms and structures designers are working on (Do & Gross, 2001). This is because sketching records conceptual ideas so that they can be revisited (Ullman, Wood & Craig, 1990). Sketching on paper is popular amongst designers during the early design phase (Aliakseyeu, 2003; Gross & Do, 1996). It offers them flexibility, is quick and encourages intuitive interactions. However, sketches are inadequate resources to build from and need to be transformed into working drawings, where considerable time is spent ensuring that plans, sections and elevations accurately represent the design in question. Ambiguous sketches can result in the flow of the design process being interrupted when they are transferred into CAD models.

However, one of the major advantages of CAD models is the precision of information about objects in terms of layout and scale, leaving more time to focus on the design process. For example, CAD software (e.g. ArchiCAD) provides designers with the ability to zoom and rotate, add materials and colours, and test stresses and tolerances before buildings are constructed.

Furthermore, the increasing globalisation of architecture, engineering and construction (AEC) projects has complicated the design process, rendering conventional manual sketching largely inadequate. Consequently, CAD modelling is increasingly used in complicated projects because it provides additional benefits including digital representation for future analysis and process integration of the model into the design tools used by other designers. CAD modelling design environments are visual and interactive. They facilitate the exploration and testing of design ideas. Photorealistic images of these models can easily be created during the design process with the addition of lighting, colour and texture-maps (Greenberg, 1991). However, Ibrahim and Rahimian (2011) argue that current CAD software is not intuitive. Therefore, much design research (Chen, 2007; Ibrahim & Rahimian, 2011; Sachse, Leinert & Hacker, 2001) has shifted focus away from individual design media to analyse designers' behaviours in mixed media design environments.

In empirical studies conducted by Chen (2007) and Ibrahim and Rahimian (2011), designers were asked to initially use traditional sketching and then to shift to CAD modelling. This form of mixed media design environments that comprise sketching and CAD modelling have proved to be more effective than any single design medium (Ibrahim & Rahimian, 2011; Sachse et al., 2001). This form of design environment (mixed media), reflects the design industry's preference and is consequently employed by contemporary design schools. However, the experiments Ibrahim and Rahimian conducted was a sequential approach of using design media, where there is some evidence that designers preferred to switch freely between media, alternating between sketching and CAD modelling. That suited them aligns with Do's concept of the 'right tool-right time' (Do, 2005: 396). This means that design environments need to provide the tools that a designer needs at that time; rather than being limited to specific design media. This shows a common agreement that switching between media is essential for mixed media design environments. This paper aims to address this issue by testing whether switching behaviours influence the roles of sketching and CAD modelling occurring in mixed media design environments. The research which involved six participants, is presented through a protocol study, switching behaviour interviews, and participants' reflections.

1 Related design studies

1.1 Individual design environments

Sketching is used not only to communicate the results of architectural designs to clients, users, legislators and constructors, but also as a central tool in the design process (Lawson, 2002). Sketching plays a pivotal role in the initiation and development of creative ideas during the early design phase. Designers rely on sketches to support and accentuate the visual reasoning necessary to explore the spatial relationships between diagrams. Initially designers brainstorm as many ideas as possible. Sketching is central to this process as raw sketches can be easily generated, revised, refined and consolidated as ideas develop. Consequently, sketches act as a conceptual tool for designers, supporting and stimulating creative ideas (Goldschmidt & Smolkov, 2006). Suwa and Tversky (2001) argued that professional designers use sketching to generate new ideas, rather than to simply express current ideas. They observed that the simple process of re-examining old sketches, including one's own and others', can lead to unexpected discoveries that generate new ideas. Sketching offers flexibility, is quick and encourages intuitive interactions, making its use popular amongst designers during conceptual design (Gross & Do, 1996).

In recent years CAD has emerged as a design tool that is capable of developing conceptual designs (Salman, Laing & Conniff, 2014). The expressive and geometric power of CAD modelling has increased to such an extent that it can be solely used from beginning to end to achieve design goals. This approach replaces traditional methods such as sketching and can be termed a digital design process. Although traditional sketching methods are low-cost, 2D sketches may not convey ideas about complicated 3D objects. For example, sketches are imprecise when multiple 2D views are used to produce a 3D perspective. In a CAD modelling design environment, 3D graphics (e.g. different angles of perspective views) can be employed to generate and manipulate 3D geometry (Oxman, 2006). CAD modelling can be meaningfully used to support problem-solving in design processes. Conventional approaches involve sketching as a means of representing basic conventions, but these are inadequate for solving complicated problems (Lin, 2001).

More recently, CAD modelling has proved to be effective AEC practices. For example, designers and clients use CAD models to review and evaluate building designs before construction (Bouchlaghem, Shang, Whyte & Ganah, 2005). This provides them with opportunities to make substantial changes at a reasonable cost. Furthermore engineers use CAD models to evaluate structural alternatives and industry professionals use them to estimate costs and to plan cost-effective construction sequences. These processes frequently unearth design conflicts that would otherwise result in expensive construction defects. For existing buildings it is often desirable to use CAD models to analyse energy properties of light and heat, to explore how a potential fire could spread, to explore potential changes in a building, and to increase the possible uses of existing building spaces (Eastman, Teicholz, Sacks & Liston, 2011). Moreover, the accurate visualisations made possible with CAD modeling may help designers alter and refine their design thinking (Salman et al., 2014).

Won's comparison of designers' visual thinking when moving between sketching and CAD modelling environments found that CAD modelling assisted a designer to shift between overall design and detailed design, although both design media supported design activities (Won, 2001). Table 1 summarises the challenges and benefits of sketching and CAD modelling during the conceptual design phase (Rahimian, Ibrahim & Jaafar, 2008).

Table 1: Challenges and benefits of sketching and CAD modelling (Rahimian, et al., 2008)

	Benefits	**Challenges**
Sketching	1. Flexibility in ideation due to tangible interface	1. Less capability to shift from micro to macro level and vice versa
	2. Easy to use	2. More tacit information flow walkthrough
	3. Easy to learn	3. Fewer visualisation details
	4. Easy to change / reform design alternatives	4. Fragile models and documents for editing or reviewing
	5. Able to use different drawing scales and possible to trade off between accuracy and clearness	5. Difficult to add and control details of design alternatives due to visualisation problems
	6. Maintains design ideas during design process Possible to review and compare all documents	6. Difficult to transition to other design stages because of format.
CAD modelling	1. Easier documentation	1. Difficulty of obtaining ability to use

2. Capability for zooming and panning for easier walkthrough	2. Arduousness of I/O devices which interrupt creativity of designers
3. Capability for temporally omitting an object or group of objects	3. Losing consistency of spaces due to lack of ability to control ubiquitous design idea in an artistic way
4. Capability for undoing undesired changes	
5. More detailed, realistic and elaborated perspectives due to high capability of visualisation	

1.2 Mixed media design environments

In recent years research has shifted from single design media to the influence of mixed media on cognitive activities during designing. Evidence for the use of mixed media comes from Sachse et al. (2001) who surveyed more than 100 expert designers who used sketching prior to and concurrently with CAD modelling. Their study identified three positive outcomes of this approach: better solutions, faster task completion, and fewer processing steps to develop CAD models. These results are supported by Chen (2007) who studied design creativity in individuals who used conventional and digital media simultaneously. Chen's results showed that, as designers switch from sketching to digital tools, design creativity is stimulated because switching behaviour causes them to re-think previous ideas and to improve the quality of their design soultions.

Ibrahim and Rahimian (2011) argued that the CAD software available at the time did not facilitate the intuitive aspects of conceptual design and they therefore investigated mixed media. They conducted a protocol study of architectural students in three discrete design environments (mixed media, sketching and CAD modelling) and found mixed media to be the most effective external representation aid because it generated higher quality solutions than either CAD modelling or sketching. However, this study focused on the evaluation of the design solutions from different design media. The roles of sketching and CAD modelling in mixed media design environments remain unclear.

In the mixed media studies (e.g. Chen, 2007; Ibrahim & Rahimian, 2011), participants followed a linear process of sketching prior to using CAD modelling. However, this is not to imply that there only one solution, since in reality, many possible solutions are generated when designing to meet specific requirements. This process involves redefining problems and developing solutions, called co-evolution by Maher, Poon and Boulanger (Maher, Poon & Boulanger, 1996) (Figure 1). This model fits Dorst and Cross's design creativity study (Dorst & Cross, 2001) in that they argue that creative design is not a matter of first defining a problem and then searching for a satisfactory solution. Creative design is a matter of the interchange of information between problems and solutions. Moreover, based on the Table 1, the benefits and challenges of sketching and CAD modelling have a complementarity relationship. For example, sketching has lower visualisation attributes whilst CAD modelling provides more detailed, realistic and elaborate perspectives. In contrast, sketches are easy to change and / or to develop alternate designs, while CAD modelling can interrupt designers' creativity due to the often restrictive nature of Input / Output devices. Therefore, design media should fit designers' needs as per Do's concept of the 'right tool-right time' (Do, 2005: 396).

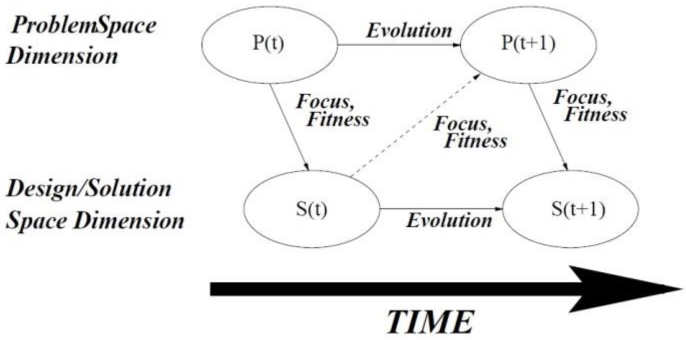


Figure 1 The co-evolution design model (Maher et al., 1996)

1.3 Hypothesis

Our proposed switching behaviour model (Figure 2) contains three types of switching behaviours that occur in mixed media design environments. The definition of these switching behaviours is shown in the following:

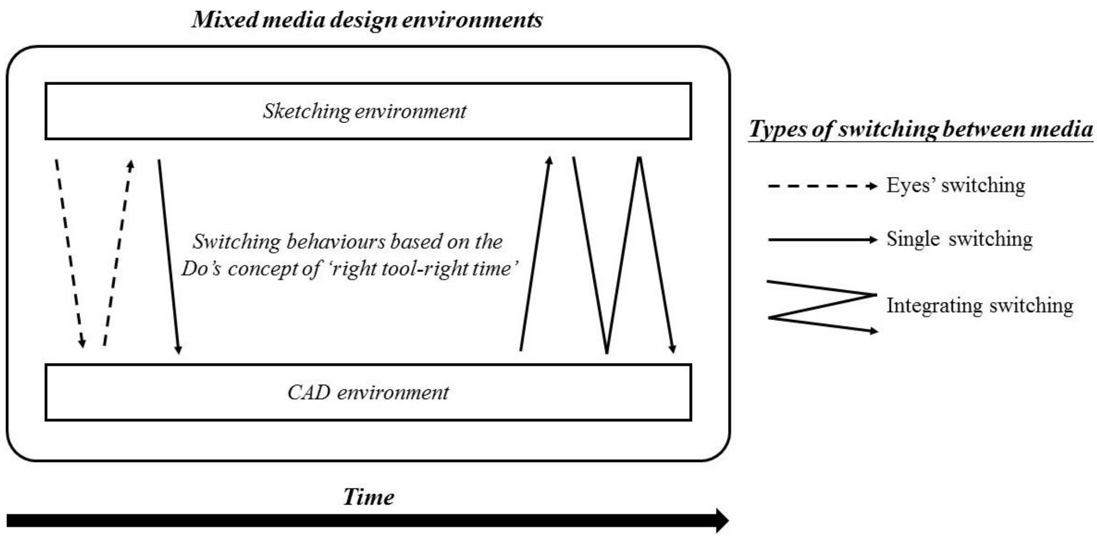


Figure 2 A switching behaviour model for mixed media design environments

Eyes' switching refers solely to where designers *look*. For instance, during the CAD modelling process, a designer may map the current CAD model with its sketched layout to enhance his/her visual thinking. *Single switching* refers to where designers *look and execute* actions. They may switch from sketching to CAD modelling or from CAD modelling to sketching to progress their work. The strengths and weakness of these media are complementary as, for example, a designer may finish ground-floor CAD models and then sketch ideas for the first-floor layout. The main difference between eyes' switching and single switching is that single switching involves moving to another design media to continue design work, whilst eyes' switching involves using the same design media by retrieving visual information from the other media. *Integrating switching* refers to where designers *look and execute actions involving multiple switches between the media*, focusing on a particular issue. For example, this may be where the designer of a stair design for circulation between two storeys through the co-evolution process.

The first type (dotted line) is called *eyes' switching* and draws on Won's visual thinking protocol study of three types of seeing to analyse design activities (Won, 2001). They are 'seeing-imaging-drawing', 'seeing-as and seeing-that' and 'seeing-total design and seeing-detailed design'. Won's results show that designers spent more time on detailed design in CAD modelling because they could easily respond to the immediate visual feedback of the CAD models. On the other hand, designers spent more time on overall design when sketching.

The second type (solid line) is called *single switching* acoording to Rahimian, Ibrahim and Jaafar's (2008) summaries of the challenges and benefits of design media to fit designers' needs. The main benefit of sketching is to help designers record and compare different ideas on paper, whilst CAD modelling helps them focus on more detailed and realistic designs. The third type (zig-zag line) is called *integrating switching* because creative design is a matter of the interchange of information between problems and solutions (Dorst & Cross, 2001). Similarly, creative design concepts are often seen as iterative developments, where design problems and solutions evolve in a mutually adapted way (Wiltschnig, Christensen & Ball, 2013). Given that the literature identifies three types of switching modes, the roles of sketching and CAD modelling become very similar in a mixed media design environment because they help a designer to achieve a goal at the appropriate time during the design process.

2 Research methodology

2.1 Protocol analysis

The credibility of a study depends upon the research method chosen and the way in which research is conducted. Protocol analysis offers a potentially effective method for the controlled observation and experimental analysis of cognitive behaviour (Gero and Tang, 2001). Protocol analysis can be used to understand design processes, knowledge used, the cognitive actions, and strategies employed. An application of protocol analysis is to ask designers how they design an artefact. However, they usually find this question difficult to answer in detail. This is because designers often retain their design thoughts in their short-term memory while designing. Many studies (Ibrahim & Rahimian 2011; Kim & Maher, 2008; Suwa & Tversky 1997) show that protocol analysis can comprehensively record designers' reasoning during the design process rather than simply relying on their design results for such insights.

There are two ways to report protocol data: retrospective and concurrent (think-aloud) verbalisation (Dorst & Dijkhuis, 1995). Generally, retrospective verbalisation means that designers perform tasks and are asked afterwards about their thought processes during their design. Another approach is to video-record design sessions and to review recordings together with the designers, thereby enabling them to interpret what happened. However, it may be difficult to remember thought processes after an activity has been completed and the usefulness of this method is limited (Newell, 1990). Another problem is that designers may present their thought processes as more coherent and intelligent than they originally were; they may not report thoughts they actually had during the design process and may instead report false memories. This may give a misleading impression of perfectly rational behaviour (Newell, 1990). Designers' retrospection means that information must be retrieved from long-term memory and then verbalised. The disadvantage of this approach is that the retrieval process may not unearth all the information that was actually experienced during the design processes.

On the other hand, the think-aloud protocol requires designers to verbalise his / her thoughts while designing (Tang, Lee & Gero, 2011; Van Someren, Barnard & Sandberth, 1994). In other words, designers explain their thoughts whilst performing the task at hand. Unlike retrospective protocols for gathering verbal data, no set questions are asked. Designers are encouraged to give a concurrent account of their thoughts and to avoid interpreting what they are doing (Gero & Tang, 2001). This method is more successful because almost all of a designer's conscious effort is aimed at achieving the design task. This restricts the opportunities for them to reflect on their design activities. As such, the data gathered are very direct; there is no delay that results in altered data. The advantages of concurrent verbalisation fit the aim of this research because this process focuses on analysing designers' cognitive actions rather than using subjective self-reports (Salman et al., 2014). Therefore, concurrent verbalisation was selected as a suitable and robust approach for this study. Protocol studies involve the following steps (Ericsson & Simon, 1993; Kan & Gero, 2008): (1) Proposing a research gap; (2) Recruiting of participants and set-up of experiments; (3) Recording the experiments; (4) Transcribing protocol data; (5) Selection and/or development of a coding scheme; (6) Encoding the protocol data; (7) Analysis of the protocol data; and (8) Interpretation of results. To obtain meaningful research outcomes, an appropriate coding scheme is important and the approach used for this study is described below.

2.2 Using the FBS coding scheme to code sketching and CAD modelling activities in the mixed media study

Gero's Function-Behaviour-Structure (FBS) framework was developed in 1990 (Gero, 1990) and has evolved over the last two decades. Many protocol design studies have adopted the FBS model to describe design processes and tasks (Gero & Kannengiesser, 2004). Some researchers argue that the definition of function has not been stable over the years and that the FBS model both describes actual designing and prescribes improved designing (Tang et al., 2011). The FBS coding scheme is defined as a process-oriented design theory in which designing is understood as a sequence of distinguishable stages.

The FBS coding scheme (Figure 3) situates designing in terms of six design issues: requirements, functions, expected behaviours, behaviours derived from structures, structures and documentation. The goal of designing is to transform a set of requirements (R) into a set of design documents (D). The function (F) of a designed object is defined as its purpose or teleology. The expected behaviour (Be) includes utterances that are associated with design issues to accomplish the function. The behaviour derived from structure (Bs) includes utterances that describe the attributes of the structures that form the design. The structure (S) comprises the components of an object and their relationships between components. A design description is never transformed directly from the function but undergoes a series of design processes among the FBS design issues. These processes include: a formulation (F→Be) which transforms functions into a set of expected behaviours; a synthesis (Be→S), wherein a structure is proposed that is likely to exhibit the expected behaviour; an analysis (S→Bs) of the structure which produces its derived behaviour; an evaluation process (Bs⇆Be) which acts between the expected behaviour and the behaviour derived from structure; and documentation (S→D), which produces the design description (Gero & Kannengiesser, 2004; Gero & McNeill, 1998). Depending on the structure, there are three types of reformulation, where new variables are introduced: reformulation of structure (S→S), reformulation of expected behaviour (S→Be), and reformulation of function (S→F). Reformulation of function is relatively rare, as it changes or redefines the design problem (Gero, 1990).

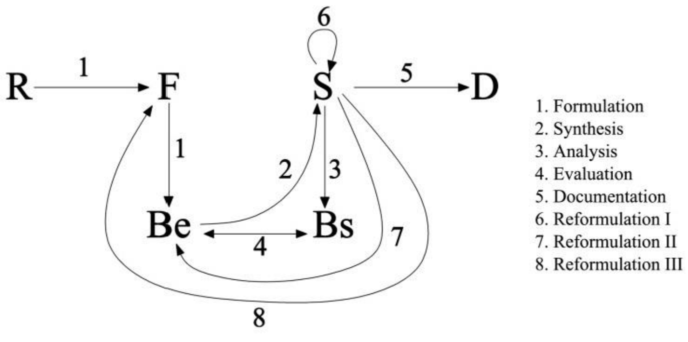


Figure 3 FBS coding scheme (Source: Gero & Kannengiesser, 2004)

The FBS coding scheme has been used as a uniform framework to represent and classify design processes in numerous studies (Tang et al., 2011; Kan & Gero, 2005 and 2009; Gero, Jiang & Williams, 2012; Williams, Lee, Gero & Paretti, 2013; Gero, Kan & Pourmohamadi, 2011). An example (Tang et al., 2011) compared the design processes of ten groups in a traditional sketching environment and in a digital sketching environment, encoding their protocol data using the scheme. The transcribed protocol data needed to be divided into small segments to facilitate the coding process. Both the content of the segments and the transitions between the segments in each environment were analysed statistically (Tang et al., 2011). The results revealed that the design processes used in digital and traditional environments were similar in terms of the speed of the design process and the design issues involved. Moreover, Kan and Gero (2005) undertook a design study demonstrating that the FBS coding scheme can be used to compare different forms of collaborative design, such as face-to-face and virtual environments. The primary advantage of the FBS coding scheme is that it provides an effective coding scheme for analysing design activities in mixed media design environments during designing.

In addition, we developed a coding scheme structure to study mixed media using the FBS design model to distinguish between the design activities that occur in sketching and in CAD modelling (Figure 4). Based on the FBS coding scheme, the sketching environment consists of six design issues (Rs, Fs, Bes, Bss, Ss, and Ds) while the CAD modelling environment also involves six design issues (Rc, Fc, Bec, Bsc, Sc and Dc). These enable different distributions of design issues to be collected and analysed.

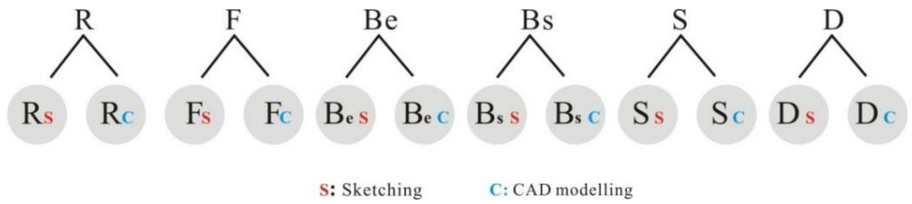


Figure 4 Development of the FBS design model for coding sketching and CAD modelling activities

The coding procedure in mixed media design environments is more difficult than it in a single design environment since designers can switch between media, so each design session is unique. We proposed the follow steps to facilitate the coding procedure. After completing a transcription, video recordings were reviewed so that utterances could be matched to the design environment used. Transcriptions of the utterances that occurred in the CAD environment (using a mouse and keyboard) were marked in green, whilst those that occurred in the sketching (with pencil and paper) were marked in red (Figure 5). After segmentation, codes (‘c’ [for CAD] and ‘s’ [for sketching]) were used to indicate which utterances occurred in which design environments.

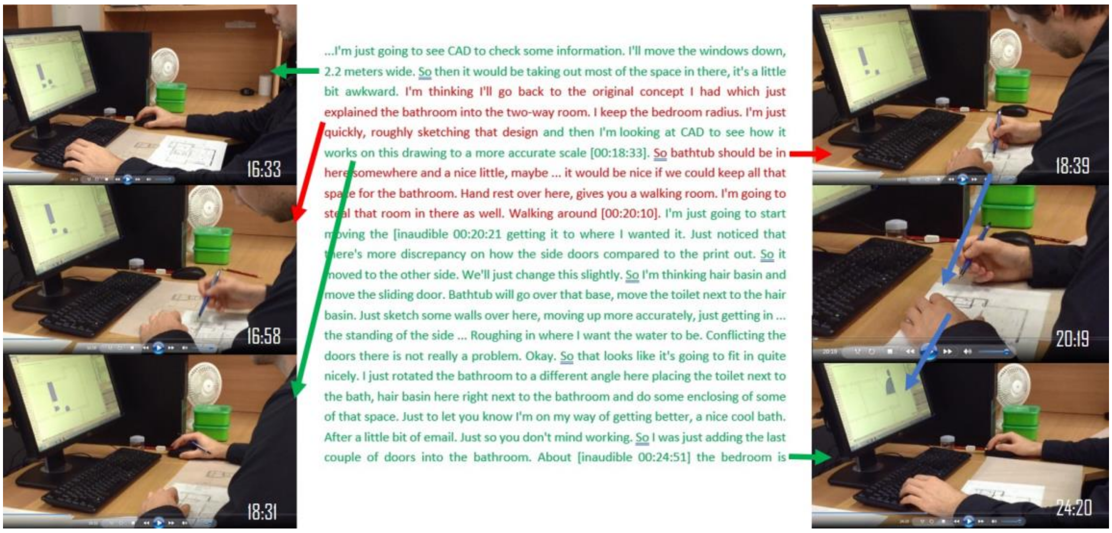


Figure 5 Coding procedure for mixed media design environments

2.3 Participant recruitment and mixed media experiment set-up

This study explores how designers interact with sketching and CAD modelling when designing. Designing is a high level cognitive activity. Most of the empirical research into designers' behaviours includes a relatively small number of participants and seeks to understand specific cognitive processes (Akin & Moustapha, 2003; Ball, Ormerod & Morley, 2004). Six designers were recruited in this study. They were initially identified from those who could best satisfy the selection criteria. To be included, the participants needed: (1) a tertiary degree in architecture with a minimum of two-years of professional architectural practical experience; (2) a design degree that had been obtained within the last three years to ensure that participants had similar design experience; (3) competence in both sketching and CAD modelling; and (4) competence in practising and communicating design in English.

Another challenge in experimental settings is the development of a design task suited to the research aims. Normally a 60 to 90-minute protocol task produces sufficient data and a manageable protocol size (Dorst, 1996). Dorst proposed that design tasks be challenging, realistic, appropriate, not too large, feasible in the time available and within the scope of knowledge of the researchers. Architectural designers often design buildings and this study provided a basic floor plan with its CAD model (Figure 6). Participants were asked to use this model to design a building for different purposes: an architectural office, a dream house and an art gallery. The three design briefs (in Appendix) were randomly assigned to designers. These tasks were appropriate because the task could be completed in approximately 75 minutes. ArchiCAD software was selected for this study as it is a popular CAD system used in design schools and industry, and it enables a designer to create a virtual building with 3D structural elements like walls, doors and other materials. Furthermore, all participants were already familiar with this software and did not require further training. The challenge was to use the 2D layout and the 3D model and produce a design for different purposes.

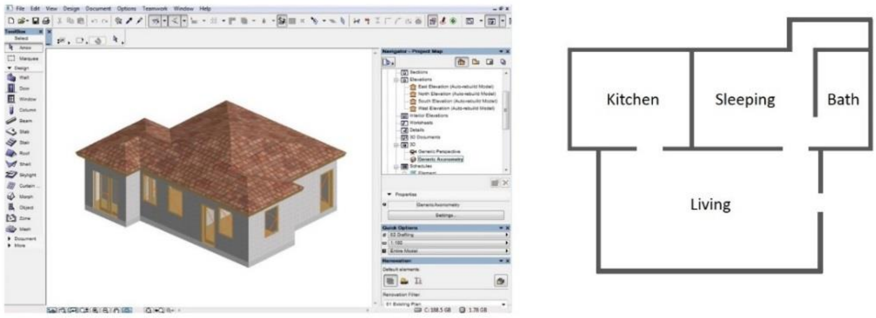


Figure 6 The experimental CAD model with its 2D layout

Figure 7 shows the equipment used in the mixed media design session. A digital video recording (DVR) system was set to record two different views on one computer screen. A camera was used to monitor a designer's behaviour, while the other view provided a video stream directly from the LCD screen. This enabled the researcher to simultaneously observe designers' switching between the design media. A typical computer configuration with a vertical screen, keyboard, mouse, pencil and paper were used. Participants could use their own laptops if they preferred. The experimental procedures allowed all participants the freedom to use both sketching and CAD modelling at will.

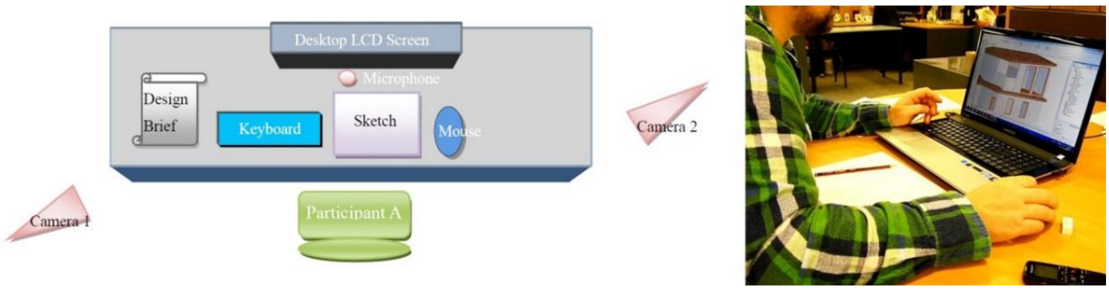


Figure 7 Experiment setup for mixed media design environments

Appropriate design protocols for this study included recording all forms of the designers' overt behaviours such as their verbalisation, sketching, CAD modelling and switching between media. We found that the think-aloud method was limited. As each switching behaviour was brief (taking only a millisecond), participants were not able to verbalise their reasons for switching. Therefore, on completion of the mixed media sessions, participants were asked to review videos of their design actions and explain the reasons for their switches. Participants' reasons for switching have been added to the transcriptions. These are shown in blue in Table 2.

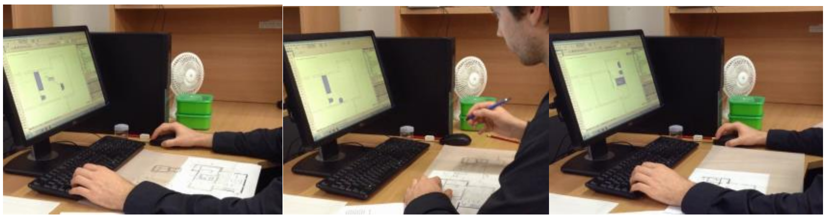
Table 2: A method to retrieve switching data

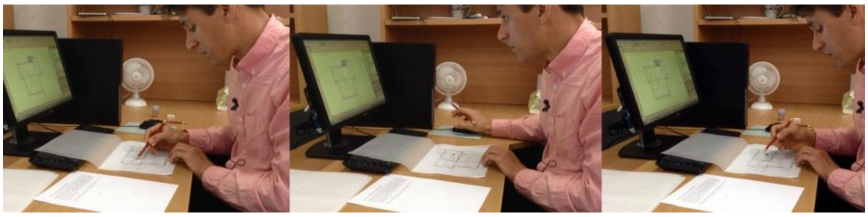
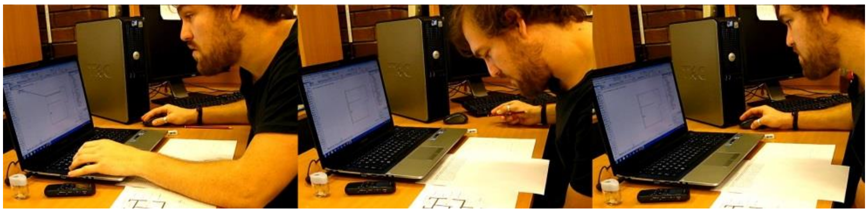
Utterances	**Recording Methods**
I'm just going to see CAD to check some information. I'll move the windows down, 2.2 meters wide. So then it would be taking out most of the space in there, it's a little bit awkward.	Think aloud

(CAD→SK) – ‘space planning in sketch’.	Interview with video
I'm thinking I'll go back to the original concept I had which just explained the bathroom into the two-way room. I keep the bedroom radius. I'm just quickly, roughly sketching that design.	Think aloud
(SK→CAD) – ‘get more accurate scale’.	Interview with video
and then I'm looking at CAD to see how it works on this drawing to a more accurate scale [00:18:33].	Think aloud
(CAD→SK) – ‘space planning, faster to sketch’.	Interview with video
So bathtub should be in here somewhere and a nice little, maybe ... it would be nice if we could keep all that space for the bathroom. Hand rest over here, gives you a walking room. I'm going to steal that room in there as well. Walking around [00:20:10].	Think aloud
(SK→CAD) – ‘conceptual plans are developed in my mind, now I am documenting in Cad to ensure they work when drawn at scale’.	Interview with video
I'm just going to start moving the [inaudible 00:20:21 getting it to where I wanted it. Just noticed that there's more discrepancy on how the side doors compared to the print out. So it moved to the other side. We'll just change this slightly. So I'm thinking hair basin and move the sliding door. Bathtub will go over that base, move the toilet next to the hair basin. Just sketch some walls over here, moving up more accurately, just getting in ... the standing of the side ...	Think aloud

In addition, Table 3 provides examples of participants’ switching behaviours.

Table 3 Examples of interview participants’ switching behaviours

Examples of switching behaviours	Interview participants’ switching behaviours
Participant A: *Integrating switching* (CAD→SK→CAD)	 ‘Try conceptual design when drawn at scale in CAD is not working properly, then try alternative sketches until finding a design that does work in CAD’.

Participant B: *Integrating switching* (CAD→SK→CAD)	 ‘I came across a design issue in CAD, something I thought was going to fit did not, and thus is was back to the drawing board to test new design ideas, and test the sketch in the cad environment’.
Participant C: *Eyes’ switching* (SK→CAD→SK)	 ‘Quick glances at computer just to clarify thinking, ideas are still being kept on the paper, being drawn’.
Participant D: *Single switching* (CAD→SK)	 ‘Got stuck on CAD modelling so using sketch to think of different space arrangement’.
Participant E: *Eyes’ switching* (CAD→SK→CAD)	 ‘I was switching back and forth between sketching and modelling environments so I can finalise my design intentions as I satisfy the briefs requirements’.
Participant F: *Single switching* (SK→CAD)	 ‘Transferring the sketch plan to the CAD environment’.

3 Analysis of results and discussion

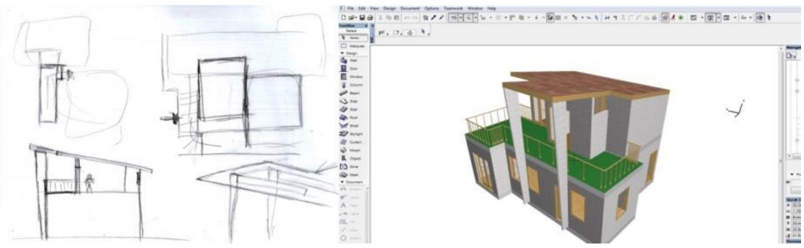
3.1 General design outcomes

Participants’ verbal accounts of their sketching and CAD modelling design sessions were recorded on video and audio equipment. Subsequently, their verbal commentary was transcribed, segmented and coded. The segmentation and coding approach linked one segment with one code (one FBS design issue) (Gero et al., 2011). If a segment was identified as having more than one FBS design issue, a further segment was needed. To improve the reliability of the protocol segmentation and coding results, the Delphi method was adopted (Gero & McNeill, 1998). Linstone and Turoff (1975) state that 'Delphi may be characterized as a method for structuring a group communication process so that the process is effective allowing a group of individuals, as a whole, to deal with a complex problem' (p.3).

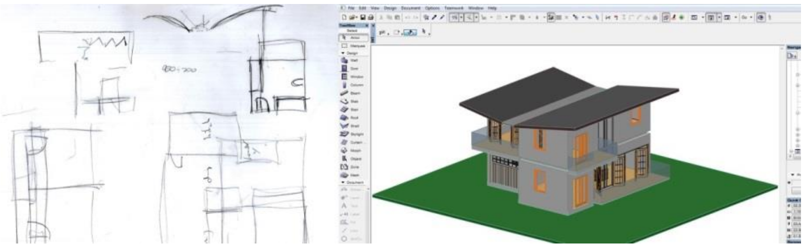
The crucial features of the Delphi method involve participants in four steps (Linstone & Turoff, 1975): (1) Exploring the issues and contributing additional information relevant to the issues; (2) Coming to an understanding of how the group views the issues; (3) Exploring significant disagreements (if any), to reveal the underlying reasons and to evaluate them; and (4) Evaluating all previously collected information. In Bilda et al.'s protocol studies (Bilda & Gero, 2007; Bilda, Gero & Purcell, 2006), the Delphi method was adopted to verify the coding segments used for analysis. The transcripts were coded twice, with a one-month period between the two coding phases. The purpose of the interval was to avoid the researcher remembering how they previously coded segments. Resolving any differences in the two rounds was a judgement call made by the researcher. Gero et al. (2012) claimed that utilising the Delphi method enabled coder reliability of 85-95% to be reached. The percentage agreement between the individual rounds and the final arbitration was approximately 88%, which confirms the reliability of the coding results of this study.

Our study also adopted Bilda et al's approach. All participants completed a design based on the briefs allocated to them (Figure 8), and their design activities were videoed. The average number of FBS design issues of the six participants was 81during sketching, and 212 codes during CAD modelling. The two sets of data collected from participants were protocols and interviews. The protocol data were generated by the think-aloud method and analysed using the FBS coding scheme, whereas following task completion, participants were shown videos of their switching behaviours and interviewed about what had occurred.

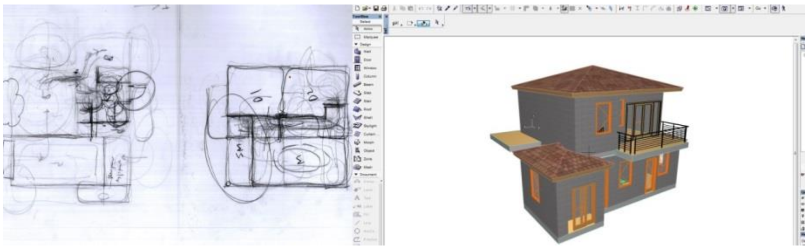
Participant A: Dream House Design



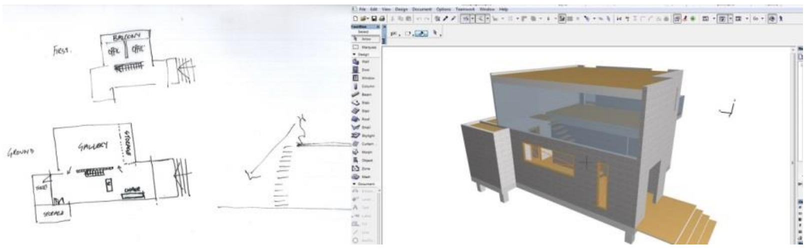
Participant B: Dream House Design



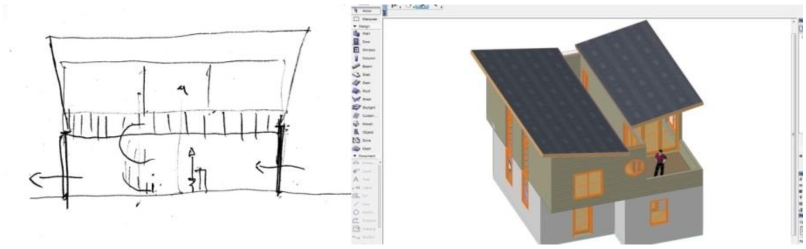
Participant C: Architectural Office Design



Participant D: Art Gallery Design



Participant E: Dream House Design



Participant F: Architectural Office Design

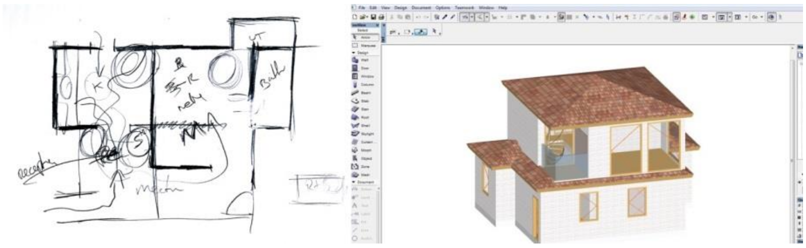


Figure 8 Design outcomes from participants

Many related studies (Gero & Tang, 2001; Bilda & Gero, 2007; Kim & Maher, 2008) adopted Suwa, Purcell and Gero's (1998) Physical-Perceptual-Functional-Conceptual (content-oriented) coding scheme to analyse interviews to understand design cognition. One of the most informative studies explored spatial cognition by comparing tangible user interfaces (TUIs) and graphical user interfaces (GUIs) and found that TUIs can enhance designers' spatial cognition (Kim & Maher, 2008). We adopted several categories from the TUIs' coding scheme (action, perception, goal and collaborative levels) to analyse switching behavioural actions. Their action-level and collaborative-level did not involve since switching itself is an action. We added a media-level to our coding scheme to characterise switching behaviours at three levels: perception, media and concept levels (Table 4).

Table 4 Switching coding scheme based on TUI's study (Kim & Maher, 2008)

Levels		Descriptions
Perception level		*Perceptual activities*
	P-visual	Attend to visual features such as scale, shape, material etc
	P-relation	Attend to objects/spaces relationship including orientation
Media level		*Environmental features*
	E-cad	An environment supports designers more detailed and realistic design features
	E-sketching	An environment supports designers to explore alternatives and to compare them
Concept level		*Focus on one intention one goal*
	G-iterations	Multiple switches by focusing one intention to achieve a goal

The TUIs part of our study used a retrospective approach. Video recordings were used as prompts to collect verbal protocols from participants. These were examined using content-oriented coding schemes to understand designers' spatial cognition. We were thus able to collect and analyse interview data relating to switching behaviours. Table 5 summarises the methods of protocol data collection and coding schemes used for the mixed media study.

Table 5 The methods of data collection and coding schemes used for the mixed media study

Types of data collection	Approaches	Coding schemes
Whole design sessions without switching interviews	Think aloud	Adopted Gero's FBS coding scheme (process-oriented)
Switching behaviours only	Interview with video aids	Three-level coding scheme (content-oriented)

3.2 The roles of sketching and CAD modelling in mixed media design environments

In section 2.2 we established that design activities in sketching and CAD modelling can be coded differently using the coding structure developed for this study (Figure 4). While (Rs) refers to sketching and (Rc) refers to CAD modelling, other examples of coding segments for sketching and CAD modelling are shown in Table 6:

Table 6 Examples of coding segments for sketching and CAD modelling

Numbers	Utterances	Code by environments
77	So now I'll put the slab down further back …	Sc
78	and over around here we can put the mezzanine level …	Sc
79	Too cool, yeah … ok, around here.	Bsc

80	It's tight, isn't it?	Bsc
81	I can't leave all that space empty … looks like a one bedroom … instead of placing a bathroom, yeah, ok, that's not going to work so …	Bsc
82	the stairs can remain in the middle.	Ss
83	Just means, I'll leave some space around there.	Ss
84	But the rooms are going to have to come forward …	Ss
85	These are not going to have room … I should ultimately figure out a way to share the bathroom.	Bss
86	You come upstairs, come to the landing and come back around … and you got the option of going left or right … the edge.	Fs

Design activity is often viewed as a problem-solving process, containing problem explorations and solution outputs (Dorst & Cross, 2001; Maher & Tang, 2003). Jiang, Gero and Yen (2014) classified FBS design issues into problem spaces and solution spaces. Reasoning about a problem space involves design issues that relate to requirement (R), function (F) and expected behaviour (Be). Reasoning about solution spaces includes behaviours derived from structure (Be) and structure (S). To understand the roles of each design medium in mixed media design environments, the coding structure used for this study was developed so that each segment could be coded into sketching or CAD modelling for the same design issues (e.g. Rs or Rc). Each design session's occurrences of design issues in sketching and CAD modelling were normalised by dividing them by the total number of design issues in that session (Table 7).

Table 7 Normalised number of design issues and their aggregated distributions (%)

		Participants								
Numbers of design issues		**A**	**B**	**C**	**D**	**E**	**F**	**Mean**	**SD**	**Aggregated (%)**
Sketching	R	4	5	6	3	3	5	4	1.2	4.9
	F	11	6	18	15	3	3	9	6.3	11.1
	Be	12	4	19	16	7	5	11	6.2	13.6
	Bs	21	9	25	43	11	12	20	12.8	24.7
	S	15	19	48	34	37	14	28	13.9	34.6
	D	2	1	4	6	15	27	9	10.1	11.1
CAD modelling	R	0	0	1	0	6	0	1	2.4	0.5
	F	30	18	9	16	2	2	13	10.8	6.1
	Be	45	23	14	11	19	6	20	13.8	9.4
	Bs	97	77	65	48	36	23	58	27.3	27.4
	S	102	103	75	79	96	61	86	17.0	40.6
	D	27	26	59	21	39	36	35	13.7	16.5

Figure 9 shows aggregated design issue distributions in sketching and CAD modelling. The six design issue distributions between sketching and CAD modelling have shared a similar pattern. It was noteworthy that the percentages for design issues of requirement (R), function (F) and expected behaviour (Be) in sketching were slightly higher than in CAD modelling. On the other hand, the percentages of design issues of behaviour derived from structure (Bs), structure (S) and design description (D) in CAD modelling were slightly higher than in sketching. In both design media, all participants expended the majority of their cognitive effort reasoning about structure (S) (34.6%~40.6%), followed by the behaviour derived from structure (Bs) (24.7%~27.4%) and then design description (D) (11.1%~16.5%). Much less cognitive effort was spent on the expected behaviour (Be) (9.4%~13.6%), the issues of function (F) (6.1%~11.1%) and requirement (R) (0.5%~4.9%). These trends suggest that participants spent more time solving a problem than in properly framing it. In general, participants' design issue distributions shared very similar behavioural patterns on both design media. We argue that this is because they facilitated the identification of a problem and the production of a solution and its necessary specifications.

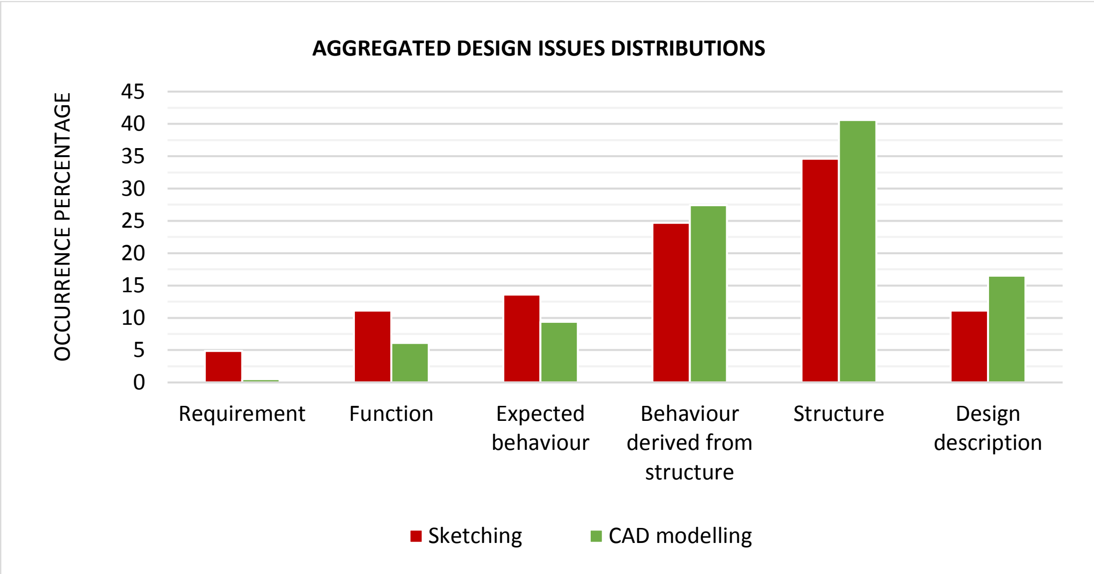


Figure 9 Aggregated FBS design issue distributions in sketching and CAD modelling

Jiang et al. (2014) proposed that problem-solution (P-S) index is a ratio measurement, computing the ratio of the total occurrences of the design issues concerned with the problem space to the sum of those related the solution space. They defined that a design session with a P-S index less than or equal to 1 as one with a solution-focused style. Whereas, a design session with the P-S index value larger than 1 as one with problem-focused style. The Equation (1) shown as follows (Jiang et al., 2014):

$$\text{P-S index} = \frac{\sum(\text{Problem}-\text{related issues})}{\sum(\text{Solution}-\text{related issues})} = \frac{\sum(R,F,Be)}{\sum(Bs,S)} \qquad (1)$$

The values of P-S index for each participant in sketching and CAD modelling are shown in Table 8. The solution-focused style occurred in both sketching and CAD modelling sessions. These results are plotted in Figure 10, below a line at the value of 1 for P-S index indicating design activities in mixed media design environments relating to a solution-focused style. CAD modelling sessions had significantly lower P-S index values than sketching sessions, demonstrating a strong tendency of focusing on solution-related issues.

Table 8 Values of P-S index

	Value of P-S index for Participants							
Environments	**1. A**	**2. B**	**3 C**	**4. D**	**5. E**	**6. F**	**Mean**	**SD**
Sketching	0.75	0.54	0.59	0.44	0.27	0.50	0.52	0.16
CAD modelling	0.38	0.23	0.17	0.21	0.20	0.10	0.22	0.09

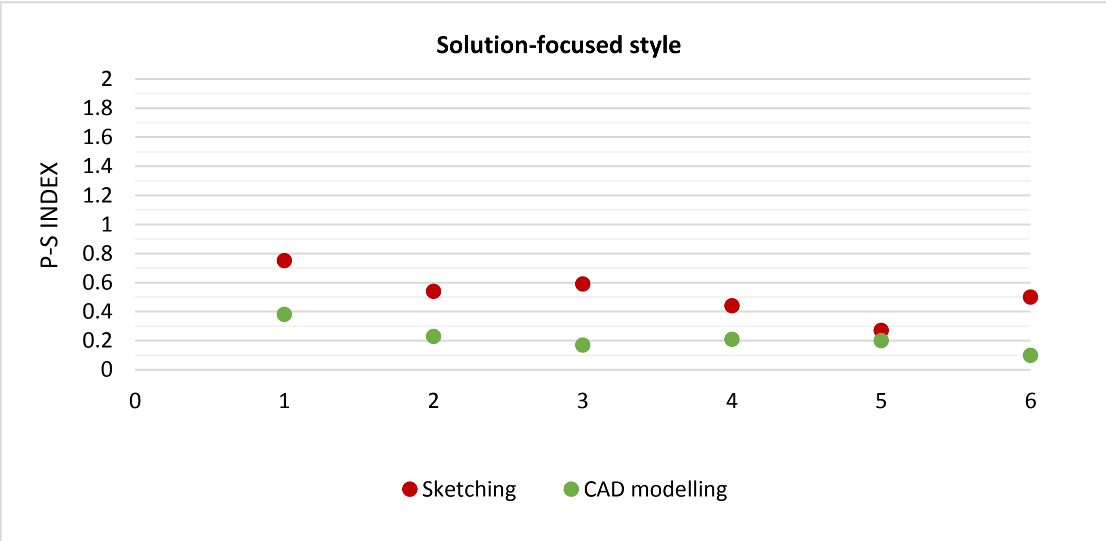


Figure 10 Values of P-S index and designing styles

A syntactic design process is one that presumes all segments are cognitively related to their immediate preceding segment. They are design processes which transform from one segment to the other (Kan and Gero, 2009; Williams et al., 2013). In this study, participants shared a similar design process distribution (Figure 10). The majority of time spent was in the design process reformulation I (17.2%~36%) and analysis (16.2%~26.2%), followed by evaluation (8.1%~32.5%) and documentation (4.5%~24.7%). Very little cognitive effort was spent on formulation (0~3.5%).

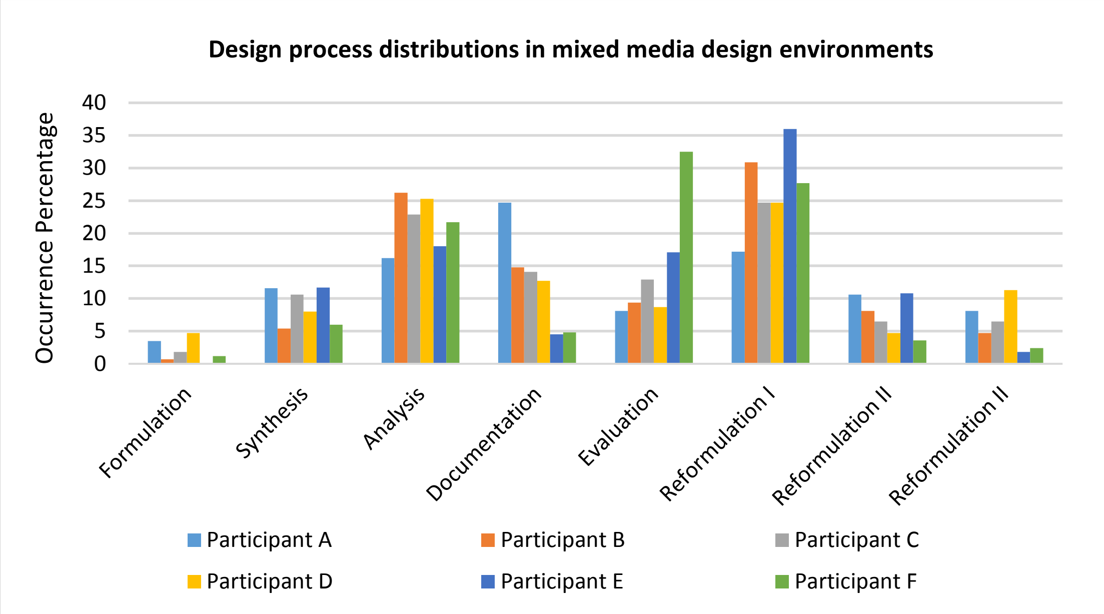


Figure 10 Each participant's design process distributions in mixed media design environments

Although each participant's reasoning process was different, the six participants had very similar patterns of design issue and design process distributions. Both design media therefore appear to serve very similar roles during designing. However, these empirical results differ from Won's comparison study of sketching and CAD modelling. Won's visual thinking study found that roles of design media are different (Won, 2001). The freedom to switch between media may change the roles of sketching and CAD in mixed media environments. The following section explores reasons for this.

3.3 Types of switching behaviours occurring during the design process

The participants switched their design behaviours between ten and twenty times during the data collection activity. Switching from one medium to another is a design process and a physical action involving 'eyes' or 'eyes and hands' movement. Normally, every switch takes a millisecond to accomplish and the participants found it difficult to verbalise their thoughts about this. The think-aloud protocol is limited to capturing what actually happens when participants switch. Therefore, interviews were conducted to explore participants' switching behaviour in detail. These were supplemented with video aids of their design tasks. These switching interviews were transcribed and coded (Table 9). Figure 11 shows the results.

Table 9 Examples of coding switching interviews

Numbers	Interviews	Codes
11	'before starting to cad a new space or idea, I like to check with my drawing in a way. "have I made a good allocation for such a space?" Then continue modelling.'	P-relation
12	'After realising the size of a car in the against the building envelope, I returned to sketch to experiment with other possible arrangements for the surrounding spaces.'	E-sketching

13	'I had placed a car in cad to give me a sense of scale of the garage as a space, I continued sketching to see if the space could be manipulated while still functioning car storage.'	P-visual
14	'I became satisfied with the few initial ideas I had drawn on paper and decided to start modelling them on the computer.'	E-cad
15	'I came across a design issue in cad, something I thought was going to fit did not, and thus is was back to the drawing board to test new design ideas, and test the sketch in the cad environment'	G-iterations
16	'Design development'	E-sketching

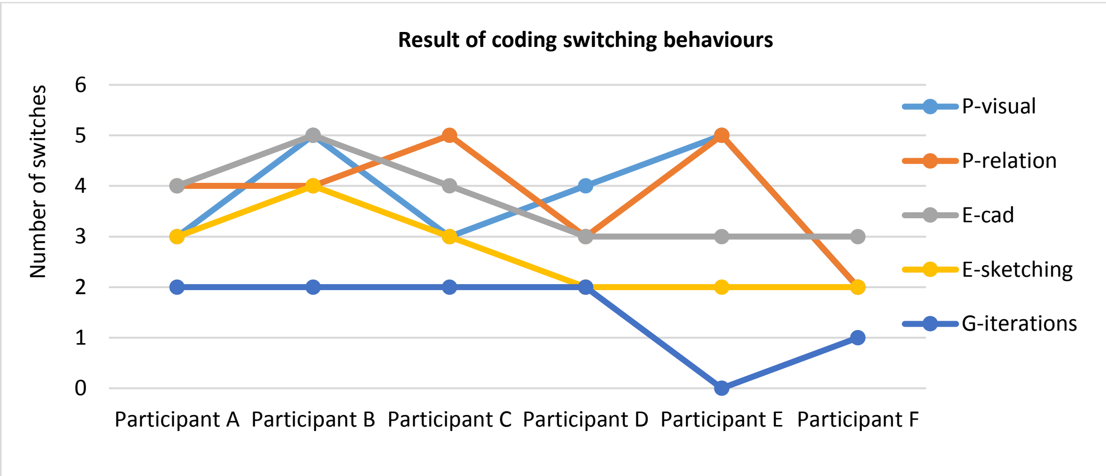


Figure 11 Results of coding switching behaviours for participants

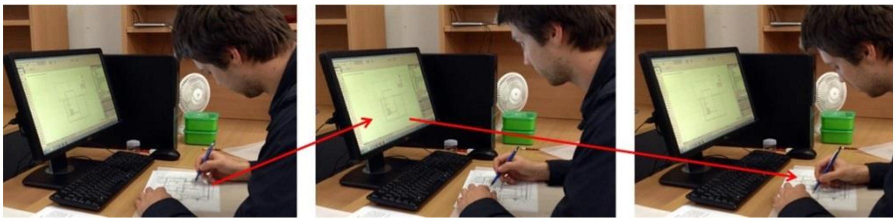
The perception level refers to the reasoning process of attending to visio-spatial features of depicted elements on CAD models (such as a sense of scale between objects) or attending to objects/spaces relationships. The CAD model layout and its visualisation were important visual cues for participants to develop designs in sketching. We called eyes' switching as P-visual. The sketches of space arrangements that occurred before using CAD helped implement the objects configuration in CAD modelling and allowed comparisons to be made between sketches and models. P-relation refers to this type of eyes' switching. It happens that after long time CAD modelling, a designer refers to sketches what she / he has already drawn on the paper. Or a designer checks a screen to retrieve CAD models information such as scale, layout, etc. to explore design alternatives during sketching. In this connection, one participant commented 'Personally, I do like to look at 3D views often when modelling to get a good idea of the project rather than sketching in 3D'. Table 10 shows that participants normally use eyes' switching between media to enhance visio-spatial ability.

Table 10 Three levels of switching behaviours

Three levels of switching behaviours

Perception level

Eyes' switching



The participant's eyes switched between media to obtain a sense of space scale.

Media level

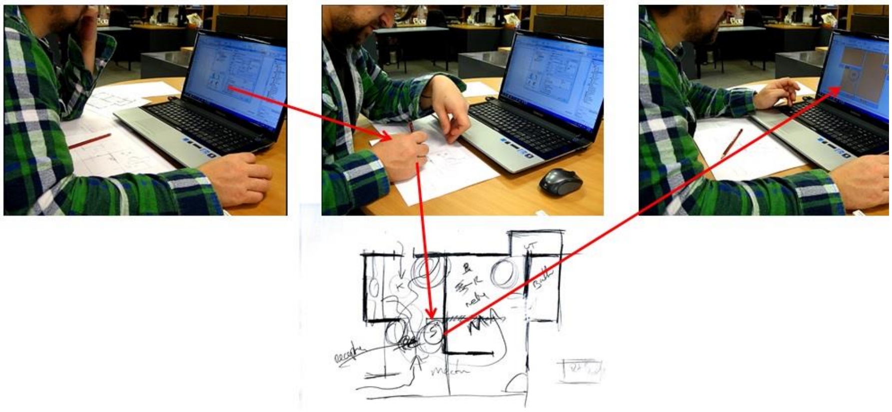
Single switching

Sketching **CAD modelling**

1. Sketching: After finishing the first-storey CAD models, the participant switched to sketching to quickly explore ideas for the second-storey layout.
2. CAD modelling: An advantage of CAD modelling is that it allows participants to understand different perspectives by rotating or zooming in/out.

Concept level

Integrating switching



The participant found it challenging to locate an appropriate place for a stair using CAD. He therefore switched to sketching to refine and evaluate different locations. Once satisfied, the participant transferred the sketches in CAD so the switching was a bridge, linking the idea development process between media.

The media level referred to in Table 10 relates to exploring interactions between design media and designers. Participants switched from sketching to CAD or from CAD to sketching (called single switching) because the effectiveness of each design medium is different. Sketching allows designers to quickly draw their ideas on paper. These drawings can then be used by designers to generate alternatives. We have called this activity E-sketching. CAD environments offer more detailed and realistic design providing designers with superior visual feedback. These CAD drawings are accurately dimensioned and to scale. They help designers evaluate the sketches developed earlier. We refer to this action as E-cad. For example, one participant identified the strengths of sketching as follows:

'It is certainly quicker and easier to sketch an idea than CAD it up. For instance, a light line on the page may just be a quick idea that ends up getting either forgotten or incorporated into the design by the drawing of progressively heavier lines, whereas… trying to do… similar things with construction lines in a CAD model takes longer, is more to draw, needs to be placed in an actual location (lines are mostly defined by coordinates) and usually needs to be actively deleted to not confuse the resulting design'.

In contrast, another participant said the following about CAD:

'Its strengths are that when one drafts one element, say the location of the wall, a range of other factors are able to be input like wall height, thickness, construction, colour and even cost and more if required... This then means that when one starts drafting the elevation some of the information is already there, and then again, in 3D the form quickly takes shape and can be viewed, checked for element clashes, zoom in and zoom out, and quickly used for perspective view'.

The concept level (Table 10) refers to the development of design goals by focusing on one intention/target (e.g. stair design and arrangement) through multiple switches to achieve the desired goal. This often happens when designers review previous drawings and are not satisfied with the outcomes in CAD models. This motivates designers to switch between media for one intonation of one goal (e.g. stair design or bathroom objects/spaces reconfiguration). An example from the data we collected, after completed the ground-level design in CAD, designers switched to sketching to explore alternatives for the first-level design. This refers to single switching. However, a designer may not be satisfied with a stair design in sketches and/or CAD models because the stair does not connect two levels and provide good circulation. The designer would then need to go back and forth focusing stair design (one intention) to solve this issue. This refers to integrating switching as G-iterations. To illustrate this, one participant said 'I felt I could achieve better results by sketching back and forth to alter in tandem with the CAD models. I believe it will allow greater conceptual freedom and exploration of ideas'. Additional feedback from another participant was that

'When designing around the placement of the stairs I found it helpful to reference the sketches I had done earlier. CAD allowed me to quickly operationalise the location of the stair using the original location (in the sketch) as the frame of reference from which I could easily deviate and modify in CAD'.

These findings match the three types of switching behaviours we proposed in section 1.3. Table 10 shows examples of switching behaviour, influencing the design process and changing the roles of sketching and CAD in mixed media design environments.

3.4 Designers' reflections and comments on participating in this study

The results of the protocol analysis using the FBS coding scheme, together with the interviews on switching behaviour provided an understanding of the roles of sketching and CAD modelling in mixed media design environments. However, it was also important to obtain participants' reflections about the experiments. Participants provided their reflections and these have been categorised into two aspects: the roles of design media and switching behaviour, and their merits throughout the design process.

Each design medium has its advantages and disadvantages, and the role of switching behaviour is to take advantages of both media, and to use each one to counter the weaknesses of the other. For instance, sketching allows designs to be prepared quickly but is not accurate, while CAD modelling is an accurate means of preparing documentation but is a time-consuming design approach. Mixed media allows a designer be fast and accurate, which supports Ibrahim and Rahimian's (2011) and Sachse et al.'s (2001) findings. Sketching is a quick way to facilitate brainstorm of ideas. When these are transferred to CAD, they are easy to change to see if the ideas work with accurate dimensions. In this connection, a participant said

> *'I feel that when ideas are more conceptual it is faster and easier to sketch, and when ideas are more developed it is faster and easier to use CAD. I feel that sketching informs the development of an idea that is then drawn in CAD for evaluation, which informs the next round of sketching and so on…. Each medium is useful for different purposes and by using both methods we can get the benefits of speed and conceptual thinking with sketching and also the accuracy and technical resolution of CAD'.*

Moreover, participants observed that mixed media allows one to quickly sketch ideas with a 'thinking hand' and then place those ideas in the digital realm. Once ideas are in a digital format, they are quick and easy to manipulate, multiply and distribute. This is faster than can be drawn manually where each alteration needs individual attention. Revising perspectives is particularly onerous by hand. This is often compared to a designer mind's eye with the actual 3D computer representation aiding the design development. For example, a participant said

> *'The combination of sketching and CAD modelling is beneficial throughout the design process. Personally, I do like to look 3D view often when modelling to get a good idea of the project rather than sketching in 3D and that would be a natural way to work for me'.*

Based on these reflections, participants were asked: 'Did you feel that switching between media benefited your design?' The common view was that switching not only allowed for a more accurate testing of conceptual sketches but also allowed designs to grow (having been facilitated by successive iterations of designs). This relates to the concept of the 'right tool-right time' (Do, 2005: 396) and that such usage would actually engage designers' thinking along creative pathways.

All participants believed strongly that switching between media is an ideal approach for conceptual design. They summarised the contribution of switching as follows:

1. Switching behaviour helps make appropriate design decisions: 'It can make your design flow smoother and allows more design decisions to be made according to the parameters of the CAD application rather than by your own sense of design. For example, one might design a kitchen by what is available in the CAD library rather than designing a kitchen based on your own thinking-hand'.

2. Switching behaviour enhances co-evolution: 'The technique I have found best is to sketch while doing the actual design exploration (being imaginative and thinking about options etc.) and then input the decisions into CAD modelling until things become unsure. At this point I print out the drawings I will find useful (plans sections elevations as appropriate) and sketch over (butter paper or straight on the page) to explore the ideas for resolving the design further. Once I have made some good decisions and am confident of the way forward I go back to the CAD and input the latest ideas by editing and adding to the information there. Then I repeat that process over and over. This way I try to avoid wasting time drafting things that will just need editing/deleting later and also avoid drafting up by hand things that will just have to be drafted again in CAD'.

3. Switching behaviour is a natural design workflow: 'Many designers use sketching, mostly as visual notes, to rapidly memorise a design idea. CAD is useful to record the ideas and extend the development of the visual notes taken whilst thinking about the design and reflecting upon the design requirements. Using CAD as a permanent record of design ideas that are ever changing on paper helped me stabilise the design workflow. For me personally it was easy and natural to switch between mediums as it forms a very natural and complementary workflow'.

4 Conclusion

Our primary goal was to better understand how switching behaviours change the roles of sketching and CAD modelling in mixed media design environments. We examined six designers' behaviours in the design process using think-aloud protocol analysis. The results show that both design mediums play a very similar design role. Although both media relate to a solution-focused style, when we compared the percentages of FBS design issues, sketching was shown to assist designers in identifying a problem (as higher percentages of R, F & Be were apparent), whereas CAD modelling provided a means to resolve the problem and offer a solution (as higher percentage of Bs and S were apparent).

A secondary goal was to see what switching behaviours occur in the design process. One difficulty was that the think-aloud method is unable to capture participants' thoughts about switches because each switch only takes a millisecond. However, participants were subsequently interviewed about each switch and reminded about their design activities by video recordings, and their reflections were collected after finishing their design tasks. The results show that switching behaviours supported designers' perception, media and concept levels during designing as this fits the concept of the 'right tool-right time' (Do, 2005: 396).

The results of this study show that concept level switching behaviour can integrate two design mediums into one. This level of switching behaviour has considerable potential to transform the design process into a creative design process, which supports Chen's (2007) findings of using conventional and digital media simultaneously. This involves an iterative switch to explore problems either in the sketching environment or in the CAD modelling environment. Solutions may then be refined using other design environments. Similarly, we hope that this research encourages further discourse on how designers intuitively interact with mixed media, and how educational programs about design (such as sketching and CAD modelling programs) integrate into one program to enhance the three levels of designers' cognition in the design process.

In empirical studies conducted by Ibrahim and Rahimian (2011), designers were asked to initially use traditional sketching before shifting to CAD modelling. This use of mixed media, in which one shift between media occurs with no backtracking allowed, is defined as Sequential Mixed Media (SMM). However, researchers (Do, 2005; Sachse et al., 2001) found that designers prefer to move freely between media, alternating at will between sketching and CAD modelling. This method is termed Alternative Mixed Media (AMM) and is a process frequently used by designers. Questions about the differences between SMM and AMM and how switching between media impacts on the design process are important areas for further study.

The current study is based on the six participants' protocols in the AMM sessions combined with switching behaviour interviews. These activities produced a large amount of data and provided opportunities to test various experimental settings. However, the sample size of this study is limited. To better understand the impact of switching behaviours on design cognition, further investigations with a larger sample size in both SMM and AMM sessions are recommended.

Acknowledgements

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References

Akin, Ö. and Moustapha H. (2003). Strategic use of representation in architectural massing. *Design Studies*, 25(1).

Aliakseyeu, D. (2003). A Computer Support Tool for the Early Stages of Architectural Design. PhD thesis, Eindhoven University of Technology, The Netherlands.

Ball, L. J., Ormerod, T. C. and Morley, N. J. (2004). Spontaneous analogising in engineering design: A comparative analysis of experts and novices. *Design Studies*, 25, 495-508.

Bilda, Z. and Gero, J. S. (2007). The impact of working memory limitations on the conceptual design process. *Design Studies* 28(4), 343-367.

Bilda, Z., Gero, J. S. and Purcell, T. (2006). To sketch or not to sketch? That is the question, *Design Studies* 27(5), 587-613.

Bouchlaghem, D., Shang, H., Whyte, J. and Ganah, A. (2005). Visualisation in architecture, engineering and construction (AEC). *Automation in Construction* 14(3) 287-295.

Chen, Z. R. (2007). How to improve creativity: Can designers improve their design creativity by using conventional and digital media simultaneously? *CAAD Futures 2007,* Australia.

Dorst, K. (1996). The design problem and its structure. *in* N. Cross, H. Christianns and K. Dorst (eds.), *Analysing Design Activity*, John Wiley & Sons Ltd, Chichester, New York, 17-35.

Dorst, K. and Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies*, 22(2), 425–437.

Dorst, K. and Dijkhuis, J. (1995). Comparing paradigms for describing design activity. *Design Studies*, 16 (2), 261-274.

Do, E. Y. L. (2005). Design sketches and sketch design tools. *Knowledge Based Systems* (18) 383-405.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). The evolution from filebased exchange to building model repositories. BIM Handbook: A guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors (2nd ed.). John Wiley & Sons Inc.

Ericsson, K. A. and Simon, H. A. (1993). *Protocol Analysis: Verbal Reports as Data.* Cambridge, Mass: MIT Press.

Gero, J. S. (1990). Design prototypes: A knowledge representation schema for design. *AI Magazine*, 11(4), 26-36.

Gero. J. S. and McNeill, T. (1998). An approach to the analysis of design protocols. *Research in Engineering Design,* Springer Verlag, London.

Gero, J. S. and Kannengiesser, U. (2004). The situated Function-Behaviour-Structure framework. *Design Studies*, 25(4), 373-391.

Gero, J. S. and Tang, H. (2001). The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of design protocols. *Design Studies*, 19(1), 21-61.

Gero, J. S., Jiang, H. and Williams, C. B. (2012). Does using different concept generation techniques change the design cognition of design students? *ASME IDETC* DETC2012-71165.

Gero, J. S., Kan, J. W. T. and Pourmohamadi, M. (2011). Analysing design protocols: Development of methods and tools. *in* A Chakrabarti (ed), *Research into Design,* Research Publishing, 3-10.

Gross, M. and E. Y., Do. (1996). Ambiguous intentions: A paper-like interface for creative design. *Proceedings of the ACM UIST Conference*, 183-192.

Goldschmidt, G. (1994). On visual design thinking: The vis kids of architecture. *Design Studies*, 15(2), 158-174.

Goldschmidt, G. and Smolkov, G. (2006). Variances in the impact of visual stimuli on design problem solving performance. *Design Studies*, 27(5), 549-569.

Greenberg, D. (1991). Computers and architecture. *Scientific American*, 264(2).

Ibrahim, R. and Rahimian, F. P. (2011). Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction*, 19(8), 978-987.

Jiang, H, Gero, J. S. and Yen, C. C. (2014). Exploring designing styles using problem-solution indexes. *in* JS Gero (ed), *Design Computing and Cognition'12,* Springer, pp. 85-101.

Kavakli, M. and Gero, J. S. (2001). Sketching as mental imagery processing. *Design Studies,* 22(4), 347-364.

Kan, J. W. T. and Gero, J. S. (2008). Acquiring information from linkography in protocol studies of designing. *Design Studies*, 29(4), 315-337.

Kan, J. W. T. and Gero, J. S. (2005). Can entropy indicate the richness of idea generation in team designing? *Proceedings of the 10th International Conference on Computer Aided Architectural Design Research in Asia* (*CAADRIA 2005*), New Delhi, India.

Kan, J. W. T. and Gero, J. S. (2009). Using the FBS ontology to capture semantic design information in design protocol studies, *in* J McDonnell and P Lloyd (eds), *About: Designing. Analysing Design Meetings,* Taylor & Francis, pp. 213-229.

Kim, M. J. and Maher, M. L. (2008). The impact of tangible user interfaces on spatial cognition during collaborative design. *Design Studies*, 29(3), 222-253.

Lawson, B. R. (2002) CAD and creativity: Does the computer really help? *Leonardo*, 35(3), 327-331.

Lin, C. Y. (2001). A digital procedure of building construction. *in* Gero, J., Chase, S. and Rosenman, M. (eds), CAADRIA2001, Key Centre of Design Computing and Cognition, University of Sydney, 459-468.

Linstone, H. A. and Turoff, M. (1975). *The Delphi Method: Techniques and Applications.* Addison-Wesley, Reading Massachusetts.

Maher, M. L., Poon, J. and Boulanger, S. (1996). Formalising design exploration as co-Evolution: A combined gene approach. *Advances in Formal Design Methods for CAD*, (ed.) John S. Gero, Chapman & Hall.

Maher, M. L. and Tang, H. H. (2003). Coevolution as a computational and cognitive model of design. *Research in Engineering Design,* 14(1), 47–63.

Newell, A. (1990). *Unified Theories of Cognition*. Cambridge, Mass: Harvard University Press.

Oxman, R. (2006). Theory and design in the first digital age. *Design Studies*, 27(3), 229-265.

Purcell, A. T. and Gero, J. S. (1998). Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology. *Design Studies*, 19(4), 389-430.

Rahimian, R. F., Ibrahim, R. and Jaffar, F. Z. (2008). Feasibility study on developing 3D sketching in virtual reality (VR) environment. *ALAM CIPTA, Int. J. Susta. Trop. Des. Res. Pract*, 3, 60-78.

Salman, H. S., Laing, R. and Conniff, A. (2014). The impact of computer aided architectural design programs on conceptual design in educational context. *Design Studies*, 35 (4), 412-439.

Sachse, P., Leinert, S. and Hacker, W. (2001). Designing with computer and sketches, *Swiss Journal of Psychology*, 60(2), 65-72.

Suwa, M. and Tversky, B. (2001). How do designers shift their focus of attention in their own sketches? *In* Anderson, M., Meyer, B. and Olivier, P. (eds.) *Diagrammatic Reasoning and Representation*, Berlin: Springer, 241-260.

Tang, H. H., Lee, Y. Y. and Gero, J. S. (2011). Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function-behaviour-structure coding scheme. *Design Studies*, 32(1), 1-29.

Ullman, D. G., Wood, S. and Craig, D. (1990). The importance of drawing in the mechanical design process. *Computers & Graphics*, 14(2), 263-274.

Van Someren, M. W., Barnard, Y. F. and Sandberth, J. A. C. (1994). The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes. London: Academic Press.

Williams, C. B., Lee, Y., Gero, J. S. and Paretti, M. (2013). Exploring the effect of the design prompt on students' design cognition, *ASME IDETC2013* DETC2013–13557.

Wiltschnig, S., Christensen, B. T. and Ball, L. J. (2013). Collaborative problem-solution co-evolution in creative design. *Design Studies*, 34 (5), 515-542.

Won, P. H. (2001). The comparison between visual thinking using computer and conventional media in the concept generation stages of design. *Automation in Construction*, 10(3), 319-325.

Appendix

Design Brief: A Two-floor Art Gallery Design

You are required to design a one-floor house into a two-floor art gallery. The gallery is for two salespeople with one manager and will focus on the customers' interaction with the space and its overall aesthetic appeal. The art gallery design must use the provided conversion task but CAD modelling such as walls, doors, etc., can be modified, added or deleted. The gallery should include a reception, big show room, kitchen, bathroom, storage room, hallway, stairs from ground-level and two working rooms with a big balcony on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style, with colour or material; but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models and within the 1-1.5hour timeline.

Design Brief: A Two-floor Architectural Office Design

You are required to design a one-floor house into a two-floor architectural office for three architects and one manager. It will need to focus on the architectural designers' interaction with the space and its overall aesthetic appeal. The office design must use the conversion task provided but CAD modelling such as walls, doors, etc., can be modified, added or deleted. This office should include a reception area, meeting room, kitchen, bathroom, garage, hallway, stairs from ground-level and two design rooms, with an open smoking area on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style with colour or material but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models.

Design Brief: A Two-floor Dream House Design

You are required to design a one-floor house into a two-floor dream house. The apartment is for a young family with one child and will focus on the users' interaction with the space and its overall aesthetic appeal. The apartment design must use the provided extension task but CAD modelling such as walls, doors, etc., can be modified, added or deleted, because the current layout does not satisfy them – for example, the female owner wants more space for the bathroom. This apartment should include a living room, kitchen, bathroom, stairs on at ground-level and two bedrooms with balconies on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style with colour or material but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models.

A Comparison of Designers' Reflections of Designing Using Sketching and CAD Modelling

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Abstract: In this paper we question whether switching behaviour impacts on the manner in which sketching and CAD modelling are used in the design process. In order to answer this question, we conducted think-aloud experiments with eight designers. They were asked to design specific artefacts using two different approaches: firstly, where they were not allowed to switch between media and secondly, where they were allowed to switch. The resulting design activities in these two conditions were compared using a protocol analysis. The results show that there is no significant difference between sketching and CAD modelling based on three assessments: design issue distributions, problem-solving index and design process distributions. One of the difficulties experienced was that the think-aloud method was unable to capture participants' thoughts about switches because each switch takes only a few milliseconds. However, participants were subsequently interviewed about each switch and reminded about their design activities using video recordings, and their reflections were collected after finishing design tasks. Six out of eight participants strongly believed that switching behaviour is essential to make use of the advantages from both media, and to use each one to counter the weaknesses of the other.

Keywords: Sketching, CAD modelling, Protocol Analysis, Design Reflection, Design Process

1. INTRODUCTION

Designers' interactions with design media have shifted from individual design mediums to multiple design media to improve design activities and outcomes. These are in response to the increased globalisation of architecture, engineering and construction (AEC) projects. In empirical studies conducted by Chen (2007) and Ibrahim and Rahimian (2011), designers were asked to initially use traditional sketching before shifting to CAD modelling. For the purpose of the study reported in this paper, this use of mixed media, in which one shift between media occurs, is defined as Sequential Mixed Media (SMM). Researchers (Sachse, Leinert & Hacker, 2001) found, however, that designers prefer to interact freely between media, alternating between sketching and CAD modelling as it suited them. This aligns with Do's concept of the 'right tool-right time' (Do, 2005: 396). Do argues that design environments need to provide the tools that a designer needs at that time; rather than being limited to specific design media. This approach is termed Alternative Mixed Media (AMM) and is currently the most popular among designers and design students.

When Ibrahim and Rahimian (2011) compared traditional sketching, computer-aided design (CAD) modelling and mixed media to assess their influence on design activities, they found that a mixed media design environment improves the quality of the ultimate design product. The mixed media design environment, comprising sketching and CAD modelling, was found to be more effective than any one design medium (Ibrahim and Rahimian, 2011; Sachse et al., 2001). This reflects the design industry's preference and consequently the most popular design tools employed by contemporary design schools. Chen (2007) found that creativity is stimulated as designers improved the ideas they sketched by subsequently using digital design environments.

Most of the understanding we have about design activities in mixed media environments is mainly based on studies of the SMM approach. Unfortunately, there have been insufficient studies utilising AMM to explore the roles of sketching and CAD modelling and how switching behaviour could impact on designers' cognition. This paper addresses these issues by comparing two different approaches of interacting with sketching and CAD modelling (SMM vs AMM) during the design process. The research contains five sections. Section 2 provides a background of related design studies involving individual design environments and mixed media design environments. Section 3 describes the empirical study conducted to answer our research questions. Section 4 analyses eight participants' protocol data using SMM and AMM approaches, switching behaviour interviews and their reflections. The final section is our conclusion.

2. RELATED DESIGN STUDIES

2.1 Individual Design Environments

Sketching is used not only to communicate the results of architectural designs to clients, users, legislators and constructors, but also as a central tool in the design process (Lawson, 2002). Sketching plays a pivotal role in the initiation and development of creative ideas during the early design phase. Designers rely on sketches to support and accentuate the visual reasoning necessary to explore the spatial relationships between diagrams. Initially designers brainstorm as many ideas as possible. Sketching is central to this process as raw sketches can be easily generated, revised, refined and consolidated as ideas develop. Consequently, sketches act as a conceptual tool for designers, supporting and stimulating creative ideas (Goldschmidt & Smolkov, 2006). Suwa and Tversky (2001) argued that professional designers use sketching to generate new ideas, rather than to simply express current ideas. They observed that the simple process of re-examining old sketches, including one's own and others', can lead to unexpected discoveries that generate new ideas. Sketching offers flexibility, is quick and encourages intuitive interactions, making its use popular amongst designers during conceptual design (Gross & Do, 1996).

In recent years CAD has emerged as a design tool that is capable of developing conceptual designs (Salman, Laing & Conniff, 2014). The expressive and geometric power of CAD modelling has increased to such an extent that it can be solely used from beginning to end to achieve design goals. This approach replaces traditional methods such as sketching and can be termed a digital design process. Although traditional sketching methods are low-cost, 2D sketches may not convey ideas about complicated 3D objects. For example, sketches are imprecise when multiple 2D views are used to produce a 3D perspective. In a CAD modelling design environment, 3D graphics (e.g. different angles of perspective views) can be employed to generate and manipulate 3D geometry (Oxman, 2006). CAD modelling can be meaningfully used to support problem-solving in design processes. Conventional approaches involve sketching as a means of representing basic conventions, but these are inadequate for solving complicated problems (Lin, 2001).

More recently, CAD modelling has proved to be effective an AEC practice. For example, designers and clients use CAD models to review and evaluate building designs before construction (Bouchlaghem, Shang, Whyte & Ganah, 2005). These models provide them with opportunities to make substantial changes at a reasonable cost. Furthermore, engineers use CAD models to evaluate structural alternatives and industry professionals use them to estimate costs and to plan cost-effective construction sequences. These processes frequently unearth design conflicts that would otherwise result in expensive construction defects.

For existing buildings it is often desirable to use CAD models to analyse energy properties of light and heat, to explore how a potential fire could spread, to explore potential changes in a building, and to increase the possible uses of existing building spaces (Eastman, Teicholz, Sacks & Liston, 2011). Moreover, the accurate visualisations made possible with CAD modeling may help designers to alter and refine their design thinking (Salman et al., 2014).

Won's comparison of designers' visual thinking when moving between sketching and CAD modelling environments found that CAD modelling assisted designers in shifting between overall design and detailed design, although both design media supported design activities (Won, 2001). Table 1 summarises the challenges and benefits of sketching and CAD modelling during the conceptual design phase (Rahimian, Ibrahim & Jaafar, 2008).

Table 1. Challenges and benefits of sketching and CAD modelling (Rahimian, et al., 2008).

	Benefits	**Challenges**
Sketching	1. Flexibility in ideation due to tangible interface	1. Less capability to shift from micro to macro level and vice versa
	2. Easy to use	2. More tacit information flow walkthrough
	3. Easy to learn	3. Fewer visualisation details
	4. Easy to change / reform design alternatives	4. Fragile models and documents for editing or reviewing
	5. Able to use different drawing scales and possible to trade off between accuracy and clearness	5. Difficult to add and control details of design alternatives due to visualisation problems
	6. Maintains design ideas during design process Possible to review and compare all documents	6. Difficult to transition to other design stages because of format.
CAD modelling	1. Easier to prepare documentation	1. Difficulty of obtaining ability to use
	2. Capability for zooming and panning for easier walkthrough	2. Arduousness of I/O devices which interrupt creativity of designers
	3. Capability for temporally omitting an object or group of objects	3. Losing consistency of spaces due to lack of ability to control ubiquitous design idea in an artistic way
	4. Capability for undoing undesired changes	
	5. More detailed, realistic and elaborated perspectives due to high capability of visualisation	

2.2 Mixed Media Design Environments

In recent years research has shifted from single design media to the influence of mixed media on cognitive activities during design. Evidence for the use of mixed media comes from Sachse et al. (2001) who surveyed more than 100 expert designers who used sketching prior to and concurrently with CAD modelling. Their study identified three positive outcomes of this approach: better solutions, faster task completion, and fewer processing steps to develop CAD models. These results are supported by Chen (2007), who studied design creativity in individuals using conventional and digital media simultaneously. Chen’s results showed that, as designers switch from sketching to digital tools, design creativity is stimulated because switching behaviour causes them to re-think previous ideas. This results in improvements to the quality of their design soultions.

Ibrahim and Rahimian (2011) argued that the CAD software available at the time did not facilitate the intuitive aspects of conceptual design and they therefore investigated mixed media. They conducted a protocol study of architectural students in three discrete design environments (mixed media, sketching and CAD modelling) and found mixed media to be the most effective external representation aid because it generated higher quality solutions than either CAD modelling or sketching. However, this study focused on evaluating design solutions from different design media. The roles of sketching and CAD modelling in mixed media design environments remain unclear.

In the mixed media studies reviewed for this paper (e.g. Chen, 2007; Ibrahim & Rahimian, 2011), participants followed a linear process of sketching prior to using CAD modelling. However, this does not to imply that there is only one solution, since in reality, many possible solutions are generated when designing to meet specific requirements. This process involves redefining problems and developing solutions, called co-evolution by Maher, Poon and Boulanger (Maher, Poon & Boulanger, 1996) (Figure 1).

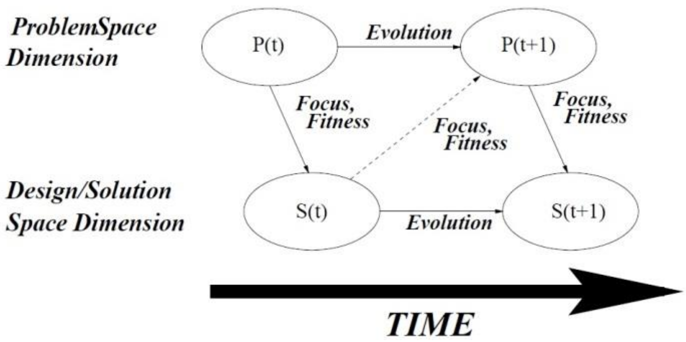


Figure 1. The co-evolution design model (Maher et al., 1996).

This model fits with Dorst and Cross's design creativity study (Dorst & Cross, 2001) in that they argue that creative design is not a matter of first defining a problem and then searching for a satisfactory solution. Creative design is a matter of the interchange of information between problems and solutions. Moreover, based on Figure 1, the benefits and challenges of sketching and CAD modelling have a complementarity relationship. For example, sketching has weak visualisation attributes whilst CAD modelling provides more detailed, realistic and elaborate perspectives. In contrast, sketches are easy to change and / or to develop alternate designs, while CAD modelling can interrupt designers' creativity due to the often restrictive nature of Input / Output devices. Therefore, design media should fit designers' needs as per Do's concept of the 'right tool-right time' (Do, 2005: 396). A review of design literature confirms the common agreement that the freedom of interacting with sketching and CAD modelling is essential. When a designer is allowed to switch between media, we suggest that the roles of sketching and CAD modelling would be very different to the designer that prohibits this switching. Our objectives are to test whether there are differences between the SMM and AMM approaches and how switching behaviour could impact on designers' cognition.

3. RESEARCH METHODOLOGY

3.1 Protocol Analysis

The credibility of a study depends upon the research method chosen and the way in which research is conducted. Protocol analysis offers a potentially effective method for the controlled observation and experimental analysis of cognitive behaviour (Gero and Tang, 2001). Protocol analysis can be used to understand design processes, knowledge used, cognitive actions, and strategies employed. An application of protocol analysis is to ask designers how they design an artefact. However, they usually find this question difficult to answer in detail. This is because designers often retain their design thoughts in their short-term memory while designing. Many studies (Ibrahim & Rahimian 2011; Kim & Maher, 2008; Suwa & Tversky, 2001) show that protocol analysis can comprehensively record designers' reasoning during the design process rather than simply relying on their design results for such insights.

There are two ways to report protocol data: retrospective and concurrent (think-aloud) verbalisation (Dorst & Dijkhuis, 1995). Generally, retrospective verbalisation means that designers perform tasks and are asked afterwards about their thought processes during their design activities. Another approach is to video-record design sessions and to review recordings together with the designers, thereby enabling them to interpret what happened. However, it may be difficult to remember thought processes after an activity has been completed and the usefulness of this method is limited (Newell, 1990). Another problem is that designers may present their thought processes as more coherent and intelligent than they originally were; they may not report the thoughts they actually had during the design process and may instead report false memories. This may give a misleading impression of perfectly rational behaviour (Newell, 1990). Retrospection means that information must be retrieved from long-term memory and then verbalised. The disadvantage of this approach is that the retrieval process may not unearth all the information that was actually experienced during the design processes.

On the other hand, the think-aloud protocol requires designers to verbalise his / her thoughts while designing (Tang, Lee & Gero, 2011; Van Someren, Barnard & Sandberth, 1994). In other words, designers explain their thoughts whilst performing the task at hand. Unlike retrospective protocols for gathering verbal data, no set questions are asked. Designers are encouraged to give a concurrent account of their thoughts and to avoid interpreting what they are doing (Gero & Tang, 2001). This method is more successful because almost all of a designer's conscious effort is aimed at achieving the design task. This restricts the opportunities for them to reflect on their design activities and to refashion their explanations of their activities. As such, the data gathered are very direct; there is no delay that results in altered data. The advantages of concurrent verbalisation fit the aim of this research because this process focuses on analysing designers' cognitive actions rather than using subjective self-reports

(Salman et al., 2014). Therefore, concurrent verbalisation was selected as a suitable and robust approach for this study. Protocol studies involve the following steps (Ericsson & Simon, 1993; Kan & Gero, 2008): (1) Proposing a research gap; (2) Recruiting of participants and set-up of experiments; (3) Recording the experiments; (4) Transcribing protocol data; (5) Selection and/or development of a coding scheme; (6) Encoding the protocol data; (7) Analysis of the protocol data; and (8) Interpretation of results. To obtain meaningful research outcomes, an appropriate coding scheme is important and the approach used for this study is described below.

3.2 Using the FBS Coding Scheme to Code Sketching and CAD Modelling in the Mixed Media Study

Gero's Function-Behaviour-Structure (FBS) framework was developed in 1990 (Gero, 1990) and has evolved over the last two decades. Many protocol design studies have adopted the FBS model to describe design processes and tasks (Gero & Kannengiesser, 2004). Some researchers argue that the definition of function has not been stable over the years and that the FBS model both describes actual designing and prescribes improved designing (Tang et al., 2011). The FBS coding scheme is defined as a process-oriented design theory in which designing is understood as a sequence of distinguishable stages. The FBS coding scheme (Figure 2) situates designing in terms of six design issues: requirements, functions, expected behaviours, behaviours derived from structures, structures and documentation.

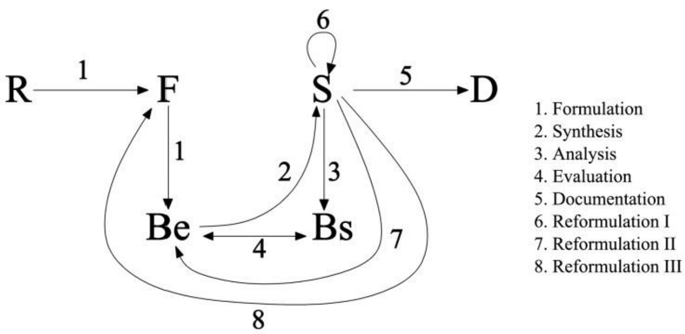


Figure 2. FBS coding scheme (Source: Gero & Kannengiesser, 2004).

The goal of designing is to transform a set of requirements (R) into a set of design documents (D). The function (F) of a designed object is defined as its purpose or teleology. The expected behaviour (Be) includes utterances that are associated with design issues to accomplish the function. The behaviour derived from structure (Bs) includes utterances that describe the suggestions of the structures that form the design. The structure (S) comprises the components of an object and their relationships between components. A design description is never transformed directly from the function but undergoes a series of design processes among the FBS design issues. These processes include: a formulation (F→Be) which transforms functions into a set of expected behaviours; a synthesis (Be→S), wherein a structure is proposed that is likely to exhibit the expected behaviour; an analysis (S→Bs) of the structure which produces its derived behaviour; an evaluation process (Bs⇆Be) which acts between the expected behaviour and the behaviour derived from structure; and documentation (S→D), which produces the design description (Gero & Kannengiesser, 2004; Gero & McNeill, 1998). Depending on the structure, there are three types of reformulation, where new variables are introduced: reformulation of structure (S→S), reformulation of expected behaviour (S→Be), and reformulation of function (S→F). Reformulation of function is relatively rare, as it changes or redefines the design problem (Gero, 1990).

In addition, we developed a coding scheme structure to study mixed media. We used the FBS design model to distinguish between the design activities that occur in sketching and those that occur in CAD modelling (Figure 3). Based on the FBS coding scheme, the sketching environment consists of six design issues (Rs, Fs, Bes, Bss, Ss, and Ds) while the CAD modelling environment also involves six design issues (Rc, Fc, Bec, Bsc, Sc and Dc). These enable different distributions of design issues to be collected and analysed.

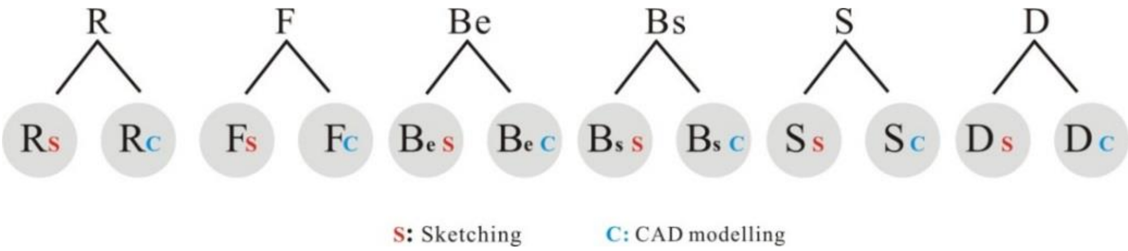


Figure 3. Development of the FBS design model for coding sketching and CAD modelling activities.

The coding procedure in mixed media design environments is more challenging than in a single design environment as designers switch between media. We adopted the following steps to facilitate the coding procedure. After completing a transcription, video recordings were reviewed so that utterances could be matched to the design environment used. Transcriptions of the utterances that occurred in the CAD environment (using a mouse and keyboard) were marked in green, whilst those that occurred in sketching (with pencil and paper) were marked in red (Figure 5). After segmentation, codes (‘c’ [for CAD] and ‘s’ [for sketching]) were used to indicate which utterances occurred in which design environments.

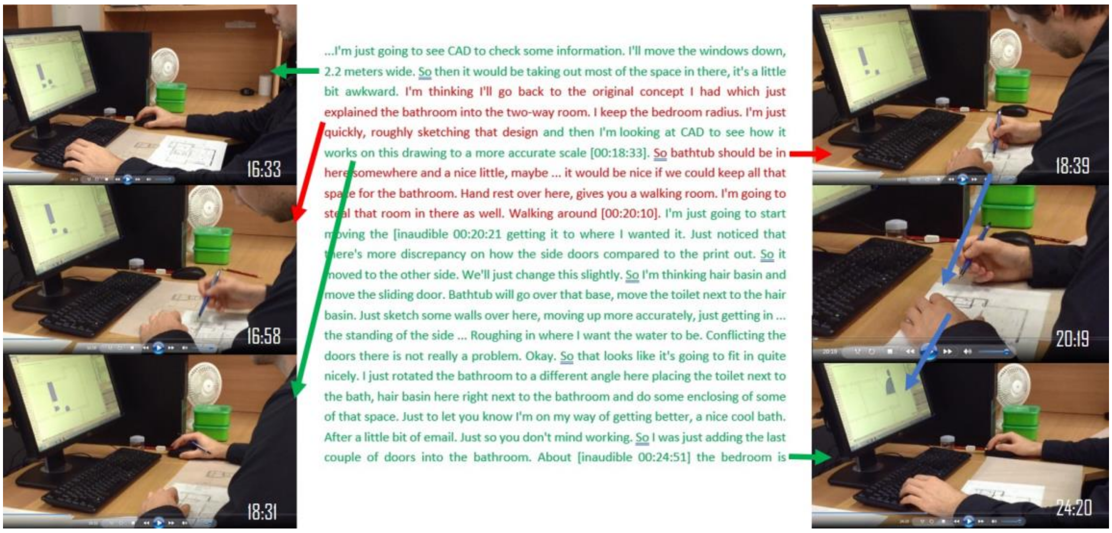


Figure 4. Coding procedure for mixed media design environments.

Appropriate design protocols for this study included recording all forms of the designers' overt behaviours such as their utterances, sketching, CAD modelling and switching between media. We found that the think-aloud method was limited. As each switching behaviour was brief (taking only a few milliseconds), participants were not able to verbalise their reasons for switching. Therefore, on completion of the mixed media sessions, participants were asked to review videos of their design actions and explain the reasons for their switches. Their reasons for switching were then added to their transcriptions. These are shown in blue in Table 2.

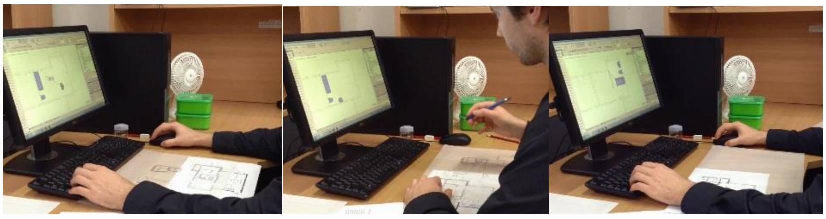
Table 2. A method to retrieve switching data.

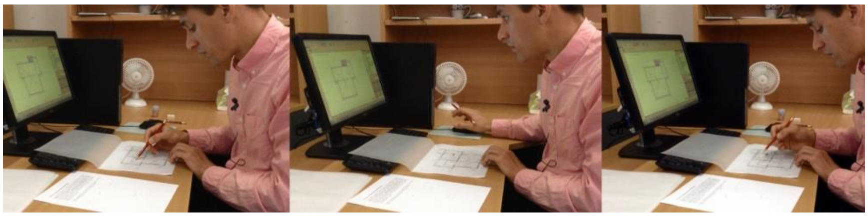
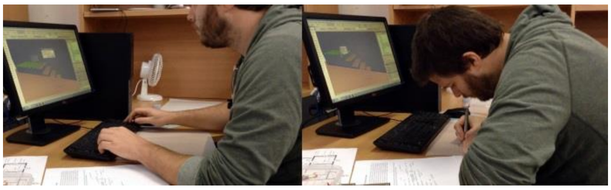
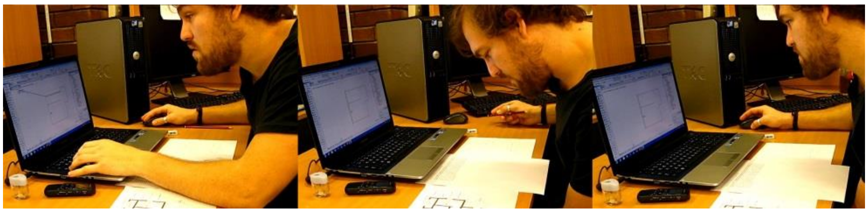
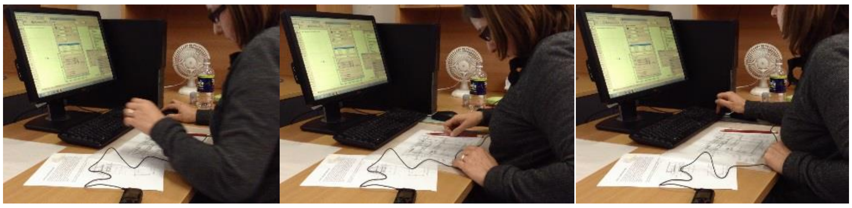
Utterances	**Recording Methods**
I'm just going to see CAD to check some information. I'll move the windows down, 2.2 meters wide. So then it would be taking out most of the space in there, it's a little bit awkward.	Think aloud
(CAD→SK) – 'space planning in sketch'.	Interview with video
I'm thinking I'll go back to the original concept I had which just explained the bathroom into the two-way room. I keep the bedroom radius. I'm just quickly, roughly sketching that design.	Think aloud
(SK→CAD) – 'get more accurate scale'.	Interview with video
and then I'm looking at CAD to see how it works on this drawing to a more accurate scale [00:18:33].	Think aloud
(CAD→SK) – 'space planning, faster to sketch'.	Interview with video

So bathtub should be in here somewhere and a nice little, maybe ... it would be nice if we could keep all that space for the bathroom. Hand rest over here, gives you a walking room. I'm going to steal that room in there as well. Walking around [00:20:10].	Think aloud
(SK→CAD) – ‘conceptual plans are developed in my mind, now I am documenting in Cad to ensure they work when drawn at scale’.	Interview with video
I'm just going to start moving the [inaudible 00:20:21 getting it to where I wanted it. Just noticed that there's more discrepancy on how the side doors compared to the print out. So it moved to the other side. We'll just change this slightly. So I'm thinking hair basin and move the sliding door. Bathtub will go over that base, move the toilet next to the hair basin. Just sketch some walls over here, moving up more accurately, just getting in ... the standing of the side ...	Think aloud

In addition, Table 3 provides examples of participants’ switching behaviours.

Table 3. Examples of interview participants’ switching behaviours.

Examples of switching behaviours	**Interview participants’ switching behaviours**
Participant A: CAD→SK→CAD	 ‘Try conceptual design when drawn at scale in CAD is not working properly, then try alternatives sketches until finding a design that does work in CAD’.
Participant B: CAD→SK→CAD	 ‘I came across a design issue in cad, something I thought was going to fit did not, and thus is was back to the drawing board to test new design ideas, and test the sketch in the cad environment’.

Participant C: SK→CAD→SK	 ‘Quick glances at computer just to clarify thinking, ideas are still being kept on the paper, being drawn’.
Participant D: CAD→SK	 ‘Got stuck on CAD modelling so using sketch to think of different space arrangement’.
Participant E: CAD→SK→CAD	 ‘I was switching back and forth between sketching and modelling environments so I can finalise my design intentions as I satisfy the briefs requirements’.
Participant F: SK→CAD	 ‘Transferring the sketch plan to the CAD environment’.
Participant G: SK→CAD→SK	 ‘Referring to the sketch and continuing modelling in CAD’.
Participant H: CAD→SK→CAD	 ‘Still trying to resolve the staircase I wanted to maximise the walls because it

	was meant to be an art gallery and I decide to stick it in the centre of the room so it would give the absolute maximum space and go up to the top of gallery but I was trying to line it up on the two sketches with the staircase and keep the front glass for the commercial premises; hating all the stairs and everything that was there in the very limited libraries. None of them I would use normally but using them because I don't have time'.

Many related studies (including Gero & Tang, 2001; Bilda & Gero, 2007; Kim & Maher, 2008) adopted Suwa, Purcell and Gero's (1998) Physical-Perceptual-Functional-Conceptual (content-oriented) coding scheme to analyse interviews to study design cognition. One of the most informative investigations explored spatial cognition by comparing tangible user interfaces (TUIs) and graphical user interfaces (GUIs) and found that TUIs can enhance designers' spatial cognition (Kim & Maher, 2008). We adopted several categories from the TUIs' coding scheme (action, perception, goal and collaborative levels) to analyse switching behavioural actions. We did not include their action-level and collaborative-level since switching itself is an action. We added a media-level to our coding scheme to characterise switching behaviours at three levels: perception, media and concept levels (Table 4).

Table 4. Switching coding scheme based on TUI's study (Kim & Maher, 2008).

Levels	**Descriptions**
Perception level	*Perceptual activities*
P-visual	Attend to visual features such as scale, shape, material etc
P-relation	Attend to objects/spaces relationship including orientation
Media level	*Environmental features*
E-cad	An environment supports designers more detailed and realistic design features
E-sketching	An environment supports designers to explore alternatives and to compare them
Concept level	*Focus on one intention one goal*
G-iterations	Multiple switches by focusing one intention to achieve a goal

The TUIs part of our study used a retrospective approach. Video recordings were used as prompts to collect verbal data from participants. These were examined using content-oriented coding schemes to understand designers' spatial cognition. We were thus able to collect and analyse interview data relating to switching behaviours. Table 5 summarises the methods of protocol data collection and coding schemes used for the mixed media study.

Table 5. The methods of data collection and coding schemes used for the mixed media study.

Types of data collection	**Approaches**	**Coding schemes**

Whole design sessions without switching interviews	Think aloud	Adopted Gero's FBS coding scheme (process-oriented)
Switching behaviours only	Interview with video aids	Three-level coding scheme (content-oriented)

3.3 Participant Recruitments and Mixed Media Experiment Set-ups

This study explores how designers interact with sketching and CAD modelling when designing. Designing is a high level cognitive activity. Most of the empirical research into designers' behaviours includes a relatively small number of participants and seeks to understand specific cognitive processes (Akin & Moustapha, 2003; Ball, Ormerod & Morley, 2004). Eight designers were recruited in this study. They were initially identified from those who could best satisfy the selection criteria. To be included, the participants needed: (1) a tertiary degree in architecture with a minimum of two-years of professional architectural practical experience; (2) competence in both sketching and CAD modelling; and (3) competence in practising and communicating design in English.

Another challenge in experimental settings is the development of a design task suited to the research aims. Normally a 60 to 90-minute protocol task produces sufficient data and a manageable protocol size (Dorst, 1996). Dorst proposed that design tasks be challenging, realistic, appropriate, not too large, feasible in the time available and within the scope of knowledge of the researchers. Architectural designers often design buildings and this study provided a basic floor plan with its CAD model (Figure 5). Participants were asked to use this model to design a building for different purposes: an architectural office, a dream house and an art gallery. The three design briefs were randomly assigned to designers. These tasks were appropriate because each task could be completed in approximately 75 minutes. ArchiCAD software was selected for this study as it is a popular CAD system used in design schools and industry, and it enables a designer to create a virtual building with 3D structural elements like walls, doors and other materials. Furthermore, all participants were already familiar with this software and did not require further training. The challenge was to use the 2D layout and the 3D model and produce a design for different purposes.

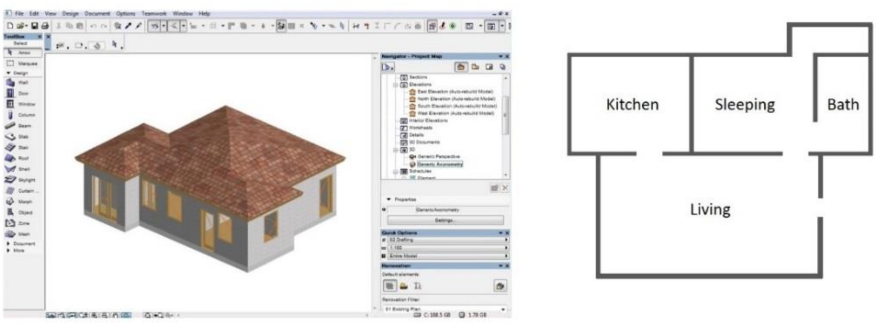
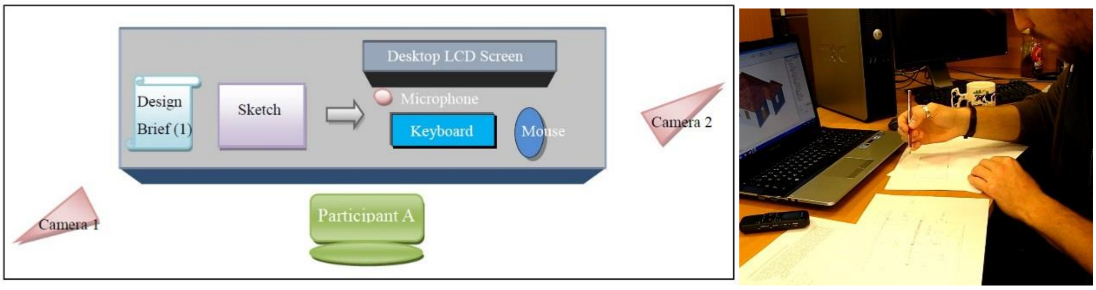


Figure 5. The experimental CAD model with its 2D layout.

Figure 6 shows the equipment used in SMM and AMM design sessions. A digital video recording (DVR) system was set to record two different views on one computer screen. A camera was used to monitor a designer's behaviour, while the other view provided a video stream directly from the designer's screen. This enabled the researcher to simultaneously observe designers' switching between the design media. A typical computer configuration with a vertical screen, keyboard, mouse, as well as pencil and paper were used. Participants could use their own laptops if they preferred. In SMM, designers were asked to use sketching and followed by CAD modelling. The experimental procedure allowed participants the freedom to use both sketching and CAD modelling at will in AMM.

SMM set-up:



AMM set-up:

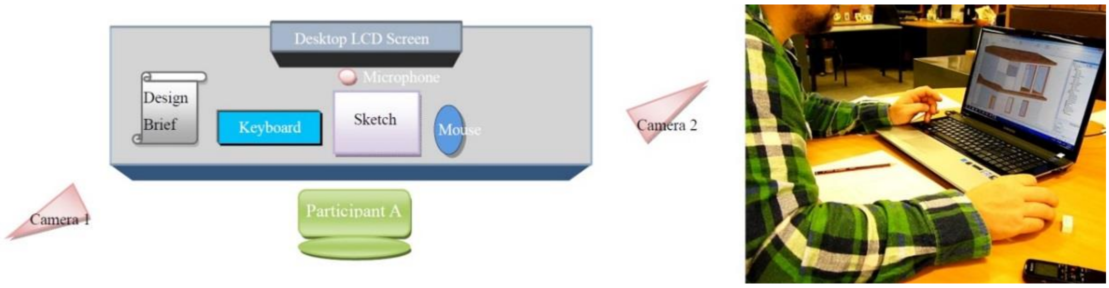


Figure 6. Experiment set-ups.

4. DATA AND DISCUSSION

4.1 General Design Outcomes

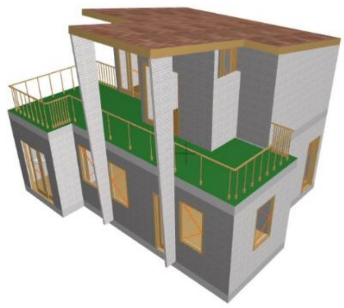
Participants' verbal accounts of their sketching and CAD modelling design sessions were recorded on video and audio equipment. Subsequently, their verbal commentary was transcribed, segmented and coded. The segmentation and coding approach linked one segment with one code (one FBS design issue) (Gero, Kan & Pourmohamadi, 2011). If a segment was identified as having more than one FBS design issue, a further segment was needed. To improve the reliability of the protocol segmentation and coding results, the Delphi method was adopted (Gero & McNeill, 1998). Linstone and Turoff (1975) state that 'Delphi may be characterized as a method for structuring a group communication process so that the process is effective allowing a group of individuals, as a whole, to deal with a complex problem' (p.3).

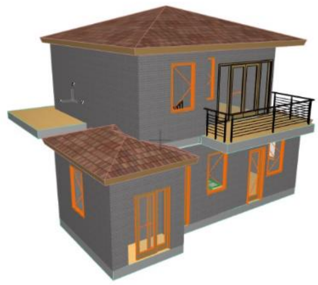
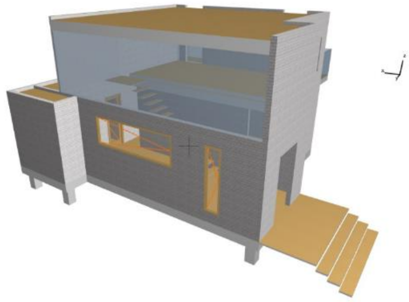
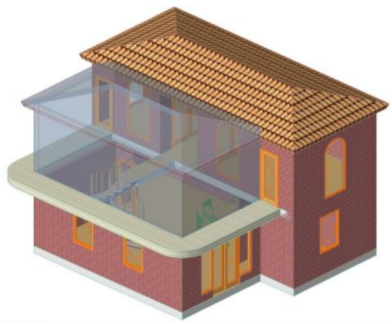
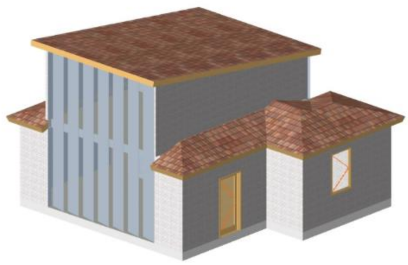
The crucial features of the Delphi method involve participants in four steps (Linstone & Turoff, 1975): (1) Exploring the issues and contributing additional information relevant to the issues; (2)

Coming to an understanding of how the group views the issues; (3) Exploring significant disagreements (if any), to reveal the underlying reasons and to evaluate them; and (4) Evaluating all previously collected information. In Bilda et al.'s protocol studies (Bilda & Gero, 2007; Bilda, Gero & Purcell, 2006), the Delphi method was adopted to verify the coding segments used for analysis. The transcripts were coded twice, with a one-month period between the two coding phases. The purpose of the interval was to avoid the researcher remembering how they previously coded segments. Resolving any differences in the two rounds was a judgement call made by the researcher. Gero, Jiang and Williams (2012) claimed that utilising the Delphi method enabled coder reliability of 85-95% to be reached. The percentage agreement between the individual rounds and the final arbitration was approximately 86%, which confirms the reliability of the coding results of this study.

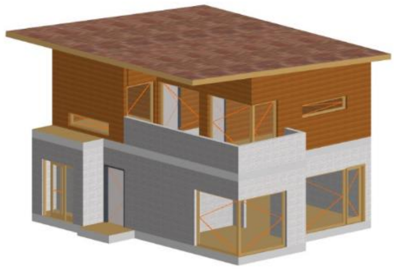
Our study also adopted Bilda et al's approach. All participants completed a design based on the briefs allocated to them (Table 6), and their design activities were videoed. The average numbers of FBS design issues of the eight participants were 78 in SMM and 80 in AMM during sketching. 167 codes occurred in SMM and 195 codes occurred in AMM during CAD modelling. The two sets of data collected from participants were protocol data and interviews. The protocol data were generated by the think-aloud method and analysed using the FBS coding scheme. Secondly, after task completion, participants were shown videos of their switching behaviours and interviewed about what had occurred.

Table 6. Design outcomes from participants.

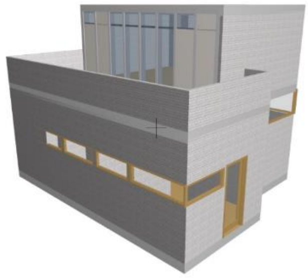
Participants	**SMM sessions**	**AMM sessions**
A	 Architecture office design	 Dream house design
B	 Architecture office design	 Dream house design

C	 Art gallery design	 Architecture office design
D	 Dream house design	 Art gallery design
E	 Architecture office design	 Dream house design
F	 Art gallery design	 Architecture office design

G

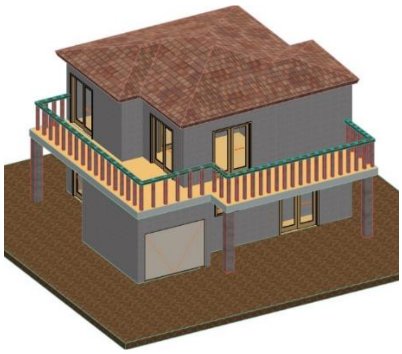


Dream house design



Art gallery design

H



Dream house design

Art gallery design

4.2 Comparison of FBS Design Issue Distributions, P-S Index and Design Process Distributions between SMM and AMM Approaches

In section 3.2 we established that design activities in sketching and CAD modelling can be coded differently using the coding structure developed for this study (Figure 3). While (Rs) refers to sketching and (Rc) refers to CAD modelling, other examples of coding segments for sketching and CAD modelling are shown in Table 7:

Table 7. Examples of coding segments for sketching and CAD modelling.

Numbers	Utterances	Code by environments
77	So now I'll put the slab down further back …	Sc
78	and over around here we can put the mezzanine level …	Sc
79	Too cool, yeah … ok, around here.	Bsc
80	It's tight isn't it?	Bsc
81	I can't leave all that space empty … looks like a one bedroom … instead of placing a bathroom, yeah, ok, that's not going to work so …	Bsc
82	the stairs can remain in the middle.	Ss
83	Just means, I'll leave some space around there.	Ss
84	But the rooms are going to have to come forward …	Ss

85	These are not going to have room … I should ultimately figure out a way to share the bathroom.	Bss
86	You come upstairs, come to the landing and come back around … and you got the option of going left or right … the edge.	Fs

Design activity is often viewed as a problem-solving process, containing problem explorations and solution outputs (Dorst & Cross, 2001; Maher & Tang, 2003). Jiang, Gero and Yen (2014) classified FBS design issues into problem spaces and solution spaces (P-S index). Reasoning about a problem space involves design issues that relate to requirement (R), function (F) and expected behaviour (Be). Reasoning about solution spaces includes behaviours derived from structure (Be) and structure (S). To understand the roles of each design medium in mixed media design environments, the codes used for this study has been developed so that each segment can be coded into sketching or CAD modelling for the same design issues (e.g. Rs or Rc). Each design session's occurrences of design issues using sketching and CAD modelling in SMM and AMM were normalised by dividing them by the total number of design issues in that session (Table 8 & Table 9).

Table 8. Normalised Number of design issues and their aggregated distributions (%) in SMM.

		Participants in SMM										
Numbers of design issues		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Mean**	**SD**	**(%)**
Sketching	R	5	2	2	5	3	14	2	0	4	4.3	5.1
	F	5	18	12	9	9	3	1	3	8	5.7	10.3
	Be	16	8	17	8	8	1	4	19	10	6.5	12.8
	Bs	28	20	27	13	16	15	7	36	20	9.5	25.6
	S	29	31	18	19	31	27	22	55	29	11.7	37.2
	D	6	1	8	3	10	21	0	4	7	6.7	8.9
CAD modelling	R	0	1	2	0	0	0	0	0	0	0.7	0
	F	4	10	14	5	1	0	1	0	4	5.2	2.4
	Be	12	15	31	8	9	6	3	14	12	8.6	7.2
	Bs	63	65	103	22	55	24	13	65	51	29.9	30.5
	S	101	118	82	55	88	55	39	73	76	26.3	45.5
	D	15	28	39	7	30	29	10	17	22	11.2	13.1

Table 9. Normalised Number of design issues and their aggregated distributions (%) in AMM.

		Participants in AMM										
Numbers of design issues		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Mean**	**SD**	**(%)**

Sketching	R	4	5	6	3	3	5	5	2	4	1.4	5
	F	11	6	18	15	3	3	5	4	8	5.8	10
	Be	12	4	19	16	7	5	10	24	12	7.1	15
	Bs	21	9	25	43	11	12	11	31	20	12.1	25
	S	15	19	48	34	37	14	22	33	28	12.1	35
	D	2	1	4	6	15	27	1	6	8	9	10
CAD modelling	R	0	0	1	0	6	0	0	0	1	2.1	0.1
	F	30	18	9	16	2	2	0	0	10	10.9	5.1
	Be	45	23	14	11	19	6	13	1	17	13.4	8.7
	Bs	97	77	65	48	36	23	37	73	57	25.1	29.2
	S	102	103	75	79	96	61	69	70	82	16.3	42.1
	D	27	26	59	21	39	36	5	17	29	16.2	14.8

All participants had similar aggregated design issue distributions for sketching and CAD modelling in SMM (Figure 7) and AMM (Figure 8). In both SMM and AMM, it was noteworthy that the percentages for design issues of requirement (R), function (F) and expected behaviour (Be) in sketching were slightly higher than in CAD modelling. In contrast, the percentages of design issues of behaviour derived from structure (Bs), structure (S) and design description (D) in CAD modelling were slightly higher than in sketching. All participants expended the majority of cognitive effort reasoning about structure (S) (SMM: 37.2~45.5%; AMM: 35~42.1%) followed by the behaviour derived from structure (Bs) (SMM: 25.6~30.5%; AMM: 25~29.2%). Much less cognitive effort was spent on issues of function (F) (SMM: 2.4~10.3%; AMM: 5.1~10%) and requirement (R) (SMM: ~5.1%; AMM: 0.1~5%). These trends suggest that participants spent more time solving a problem than in properly framing it. In general, participants' design issue distributions shared very similar behavioural patterns using sketching and CAD modelling.

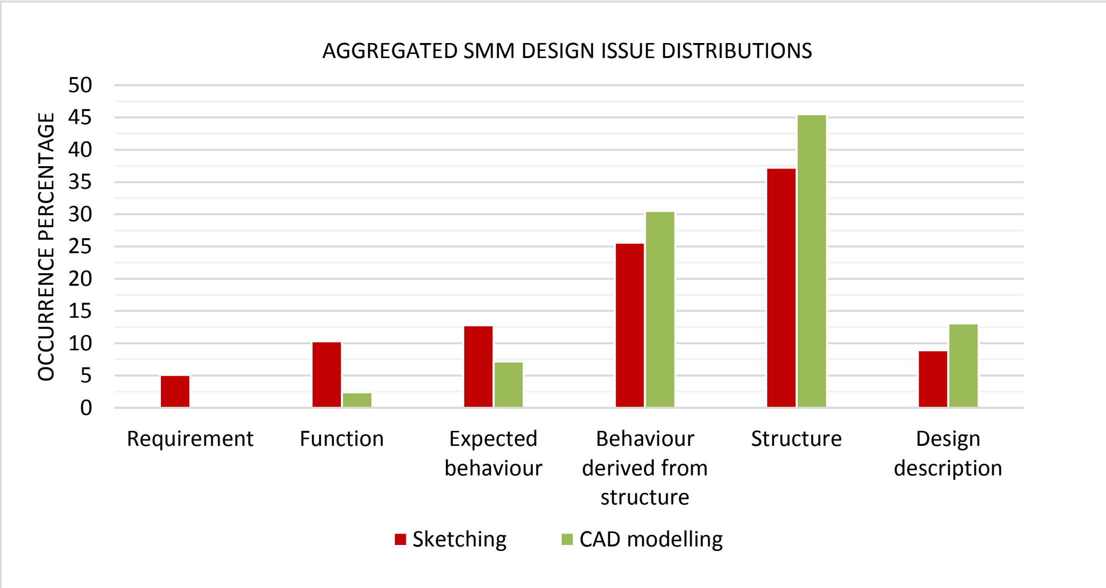


Figure 7. Aggregated design issue distributions (%) in SMM.

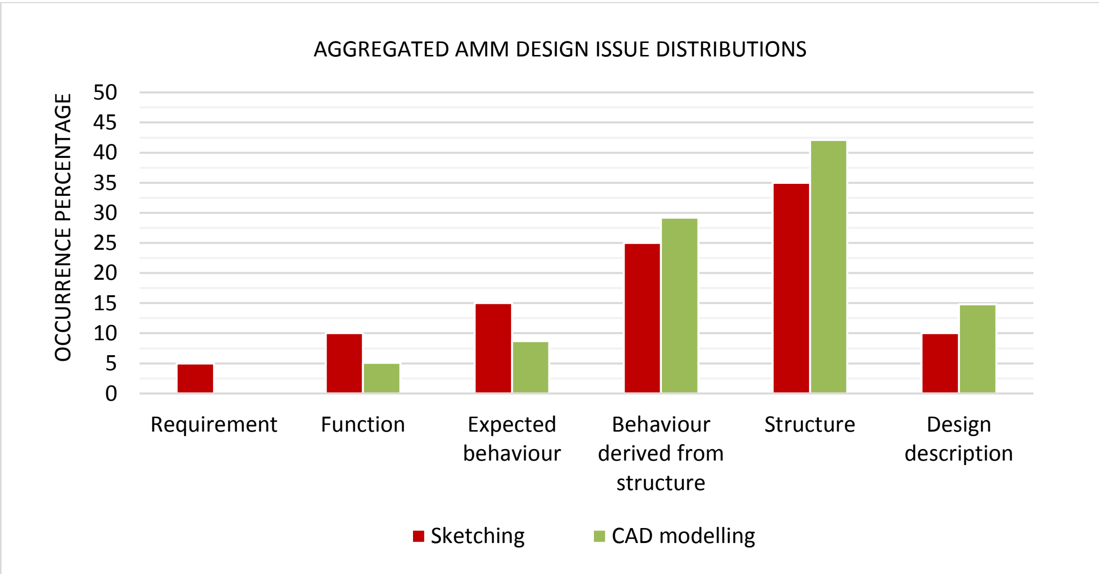


Figure 8. Aggregated design issue distributions (%) in AMM.

Jiang et al. (2014) proposed the problem-solution (P-S) index as a ratio measurement, computing the ratio of the total occurrences of the design issues concerned with the problem space to the sum of those related to the solution space. They argued that a design session with a P-S index less than or equal to 1 was one with a solution-focused style. Whereas, a design session with the P-S index value larger than 1 was one with a problem-focused style. Equation (1) illustrates this (Jiang et al., 2014):

$$\text{P-S index} = \frac{\sum(\text{Problem−related issues})}{\sum(\text{Solution−related issues})} = \frac{\sum(R,F,Be)}{\sum(Bs,S)} \qquad (1)$$

The values of the P-S index for each participant using sketching and CAD modelling in SMM are shown in Table 10, indicating that a solution-focused style occurred in these sessions. These results are also plotted in Figure 9, below a line at the value of 1 for P-S index, indicating design activities when using sketching and CAD modelling relating to solution-focused style. CAD modelling sessions (Mean: 0.12) had significant lower P-S index values than sketching sessions (Mean: 0.47), demonstrating a strong tendency to focus on solution-related issues.

Table 10. Values of P-S index in SMM.

Value of P-S index for Participants in SMM										
Environments	**1.A**	**2.B**	**3.C**	**4.D**	**5.E**	**6.F**	**7.G**	**8.H**	**Mean**	**SD**
Sketching	0.46	0.55	0.69	0.69	0.43	0.43	0.24	0.24	0.47	0.17
CAD modelling	0.1	0.14	0.25	0.17	0.07	0.08	0.08	0.1	0.12	0.06

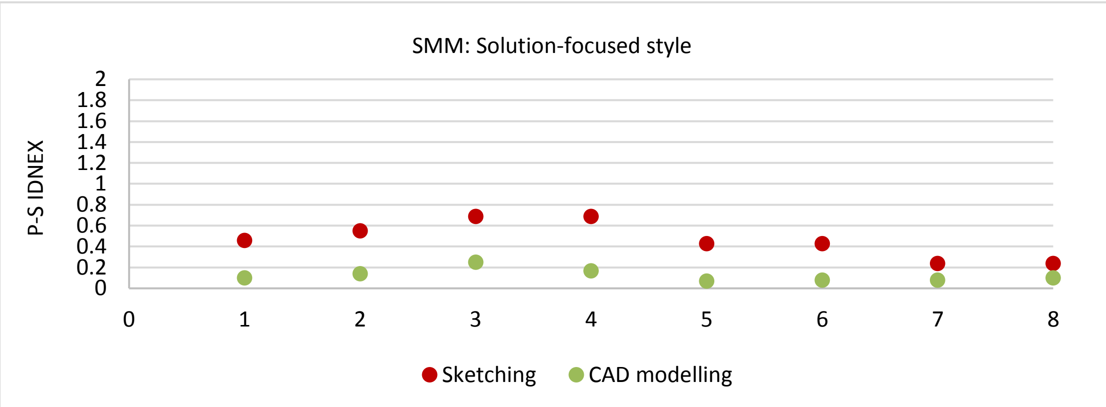


Figure 9. Values of P-S index and designing styles in SMM.

The values of the P-S index for each participant using sketching and CAD modelling in AMM are given in Table 11, showing that a solution-focused style occurred in these sessions. The results are also plotted in Figure 10, below a line at the value of 1 for P-S index, indicating design activities when using sketching and CAD modelling relating to solution-focused style. CAD modelling sessions (Mean: 0.18) had significantly lower P-S index values than sketching sessions (Mean: 0.52), demonstrating a strong tendency to focus on solution-related issues. The values of P-S index in SMM and AMM were very similar in terms of sketching and CAD modelling.

Table 11. Values of P-S index in AMM.

Value of P-S index for Participants in AMM										
Environments	**1.A**	**2.B**	**3.C**	**4.D**	**5.E**	**6.F**	**7.G**	**8.H**	**Mean**	**SD**
Sketching	0.75	0.54	0.59	0.44	0.27	0.5	0.6	0.47	0.52	0.14
CAD	0.38	0.23	0.17	0.21	0.2	0.1	0.12	0.01	0.18	0.11

modelling		

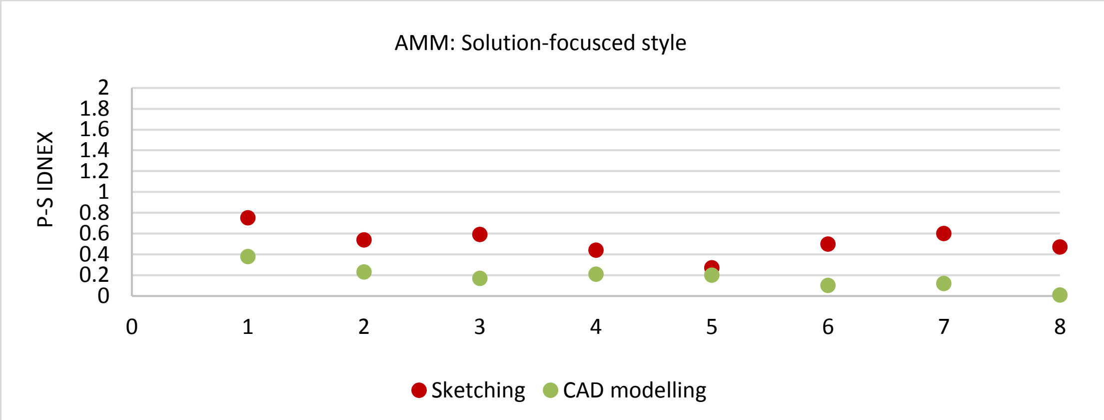


Figure 10. Values of P-S index and designing styles in AMM.

A syntactic design process is one that presumes all segments are cognitively related to their immediate preceding segment. They are design processes which transform from one segment to the other (Williams, Lee, Gero and and Paretti, 2013). Table 12 shows each participant's design process distributions (%) in SMM and AMM. In this study, participants shared very similar design process distributions in SMM and AMM (Figure 11). The majority of time spent was in the aggregated design processes of reformulation I (SMM: 38.5%; AMM: 28.4%) and analysis (SMM: 22.8%; AMM: 24%), followed by documentation (SMM: 12.1%; AMM: 12.7%) and evaluation (SMM: 9.9%; AMM: 12.1%). Much less cognitive effort was spent on formulation (SMM & AMM: 1.8%).

Table 12. Each participant's design process distributions (%) in SMM and AMM.

Participants' design process distributions (%) in SMM										
	A	B	C	D	E	F	G	H	Mean	SD
Formulation	1.2	1.8	3.7	4.6	2.2	0	0	0.6	1.8	1.7
Synthesis	6.7	6.0	7.9	10.3	7.2	4.4	3.1	6.4	6.5	2.2
Analysis	26.2	24.6	23.2	18.4	25.9	20.0	14.1	30.1	22.8	5.1
Documentation	14.0	8.4	29.3	8.0	6.5	5.6	6.2	19.1	12.1	8.3
Evaluation	4.3	6.0	11.0	6.9	13.7	26.7	4.7	5.8	9.9	7.5
Reformulation I	39.6	43.1	16.5	39.1	36.0	40.0	65.6	28.3	38.5	13.9
Reformulation II	7.9	5.4	3.0	5.7	3.6	1.1	4.7	8.7	5.0	2.5
Reformulation III	0	4.8	5.5	6.9	5.0	2.2	1.6	1.2	3.4	2.5
Participants' design process distributions (%) in AMM										
	A	B	C	D	E	F	G	H	Mean	SD
Formulation	3.5	0.7	1.8	4.7	0	1.2	1.7	0.8	1.8	1.6

Synthesis	11.6	5.4	10.6	8.0	11.7	6.0	9.4	5.7	8.6	2.6
Analysis	16.2	26.2	22.9	25.3	18.0	21.7	22.2	39.8	24.0	7.2
Documentation	24.7	14.8	14.1	12.7	4.5	4.8	11.1	14.6	12.7	6.4
Evaluation	8.1	9.4	12.9	8.7	17.1	32.5	0.9	7.3	12.1	9.5
Reformulation I	17.2	30.9	24.7	24.7	36.0	27.7	45.3	20.3	28.4	9
Reformulation II	10.6	8.1	6.5	4.7	10.8	3.6	9.4	8.9	7.8	2.7
Reformulation III	8.1	4.7	6.5	11.3	1.8	2.4	0	2.4	4.7	3.8

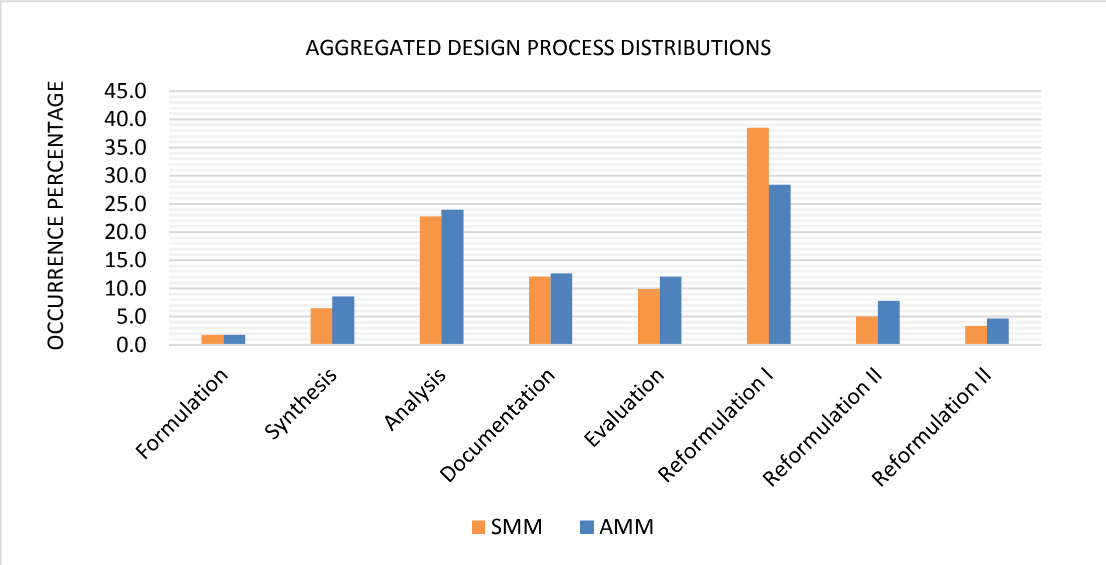


Figure 11. Aggregated design process distributions (%) in SMM and AMM.

Although this study has shown that there were no significant differences between SMM and AMM in terms of design issue distributions, P-S index and design process distributions, it is important to understand participants' reflections on sketching and CAD modelling the design tasks. The following section provides an analysis of these data.

4.3 Designers' Reflections of Using Two Approaches of Interacting with Sketching and CAD Modelling

Although a couple of designers were satisfied with the SMM approach, most felt that it was difficult to complete the tasks without switching between media. During the interviews they identified several drawbacks to the SMM approach. Designers were asked to sketch first, followed by CAD modelling. This resulted in sketching being mainly used for design and CAD modelling being used mainly for documentation. This was mentioned by participant E.

'I found this method difficult as it does not suite my natural design behaviour. I felt restricted to

the CAD tools available to me, only using them for documentation'. (Participant E)

Participant C and F argued that CAD modelling could help with some specific design issues while sketches helped in documenting design for a designer's own record.

'By restricting the process to the sketching as design and then CAD as documentation only and no allowance to switch between them the capacity of each form is limited. Some design will always happen in the CAD environment, and some documentation (even if only for the designer's own records) will happen best with pencil and paper, so assuming that the division is clear and discreet is wrong. It is generally not possible to memorize a design and then CAD it up correctly, so referring to the sketch is vital'. (Participant C)

'It did present some difficulties. As a designer one naturally reflects through interacting with representational media. Initially sketching helps recall and store ideas. Today, as a designer I often sketch, and a lot. The integration with computers and CAD in particular has not been difficult but one establishes workflows that accommodate the new tools such as CAD with sketching and ideation. By isolating the workflow, it made it difficult quickly switch between ideas and rapidly formulate responses'. (Participant F)

It was felt that by isolating the workflow, CAD modelling becomes less intuitive in terms of idea exploration and slows down the design process (Participants A & B).

'Much more difficult. Without being able to switch it took too long to try different design combinations if the first design didn't fit within the building properly. Then I was left to try to design straight into CAD which is much less intuitive than sketching'. (Participant A)

'I personally found the SMM process more difficult as once I had sketched my ideas and then placed them in CAD I could not sketch further ideas. The problem with SMM is the practitioner need to 'fix' encountered problems on the screen and not draw by hand possible alternative solutions. This process is much slower then returning to the 'thinking hand' for developing new ideas'. (Participant B)

In addition, participants provided their reflections of AMM and these have been categorised into two aspects: the roles of design media and switching behaviour, and their merits throughout the design process. Each design medium has its advantages and disadvantages. More importantly, the role of switching behaviour is to make use of the advantages from both media, and to use each one to counter the weaknesses of the other. For instance, sketching allows designs to be prepared quickly but is not accurate, while CAD modelling is an accurate means of preparing documentation but is a slow method of preparing designs. Mixed media allows a designer be fast and accurate, which supports Ibrahim and Rahimian's (2011) and Sachse et al.'s (2001) findings. It is usually faster to brainstorm ideas using sketching, and then easier to change in CAD modelling to see if the ideas work with accurate dimensions. In this connection, a participant said:

> *'I feel that when ideas are more conceptual it is faster and easier to sketch, and when ideas are more developed it is faster and easier to use CAD. I feel that sketching informs the development of an idea that is then drawn in CAD for evaluation, which informs the next round of sketching and so on…. Each medium is useful for different purposes and by using both methods we can get the benefits of speed and conceptual thinking with sketching and also the accuracy and technical resolution of CAD'. (Participant A)*

Participants observed that mixed media allows one to quickly sketch ideas with a 'thinking hand' and then place those ideas in the digital realm. They observed that, once particular ideas are placed on the screen it is quick and easy to manipulate, multiply and distribute them. This is faster than a designer can draw each possible alteration, especially in perspective. This is often compared to a designer mind's eye with the actual 3D computer representation aiding in the design development. For example, a participant said:

> *'The combination of sketching and CAD modelling is beneficial throughout the design process. Personally, I do like to look 3D view often when modelling to get a good idea of the project rather than sketching in 3D and that would be a natural way to work for me'. (Participant C)*

Based on these reflections, participants were asked a question: 'Did you feel that switching between media benefited your design?*'* The common view was that switching not only allowed for a more accurate testing of conceptual sketches but also allowed designs to grow (having been facilitated by the back and forth feeding of designs). This relates to the concept of the 'right tool-right time', (Do, 2005: 396) and that such usage would actually engage designers' thinking along creative pathways. All participants believed strongly that switching between media was an ideal approach for conceptual design. They summarised the contribution of switching as follows:

1. Switching behaviour helps make appropriate design decisions: 'It can make your design flow smoother and allows more design decisions to be made according to the parameters of the CAD application rather than by your own sense of design. For example, one might design a kitchen by what is available in the CAD library rather than designing a kitchen based on your own thinking-hand'.

2. Switching behaviour enhances co-evolution: 'The technique I have found best is to sketch while doing the actual design exploration (being imaginative and thinking about options etc.) and then input

the decisions into CAD modelling until things become unsure. At this point I print out the drawings I will find useful (plans sections elevations as appropriate) and sketch over (butter paper or straight on the page) to explore the ideas for resolving the design further. Once I have made some good decisions and am confident of the way forward I go back to the CAD and input the latest ideas by editing and adding to the information there. Then I repeat that process over and over. This way I try to avoid wasting time drafting things that will just need editing/deleting later and also avoid drafting up by hand things that will just have to be drafted again in CAD'.

3. Switching behaviour is a natural design workflow: 'Many designers use sketching, mostly as visual notes, to rapidly memorise a design idea. CAD is useful to record the ideas and extend the development of the visual notes taken whilst thinking about the design and reflecting upon the design requirements. Using CAD as a permanent record of design ideas that are ever changing on paper helped me stabilise the design workflow. For me personally it was easy and natural to switch between mediums as it forms a very natural and complementary workflow'.

4.4 The Impact of Switching Behaviours on Designers' Cognition and Creative Design Processes

The participants switched their design behaviours between ten and twenty times during the data collection activity. Switching from one medium to another is a design process and a physical action involving 'eyes' or 'eyes and hands' movement. Normally, every switch takes a few milliseconds to accomplish and the participants found it difficult to verbalise their thoughts about this. The think-aloud protocol is limited to capturing what actually happens when participants switch. Therefore, interviews were conducted to explore participants' switching behaviour in detail. These were supplemented with video aids of their design tasks. These switching interviews were transcribed and coded (Table 13). Figure 12 shows the results.

Table 13. Examples of coding switching interviews.

Numbers	Interviews	Codes
11	'before starting to CAD a new space or idea, I like to check with my drawing in a way. "have I made a good allocation for such a space?" Then continue modelling.'	P-relation
12	'After realising the size of a car in the against the building envelope, I returned to sketch to experiment with other possible arrangements for the surrounding spaces.'	E-sketching
13	'I had placed a car in cad to give me a sense of scale of the garage as a space, I continued sketching to see if the space could be manipulated while still functioning car storage.'	P-visual
14	'I became satisfied with the few initial ideas I had drawn on paper and decided to start modelling them on the computer.'	E-cad

15	'I came across a design issue in cad, something I thought was going to fit did not, and thus is was back to the drawing board to test new design ideas, and test the sketch in the cad environment'	G-iterations
16	'Design development'	E-sketching

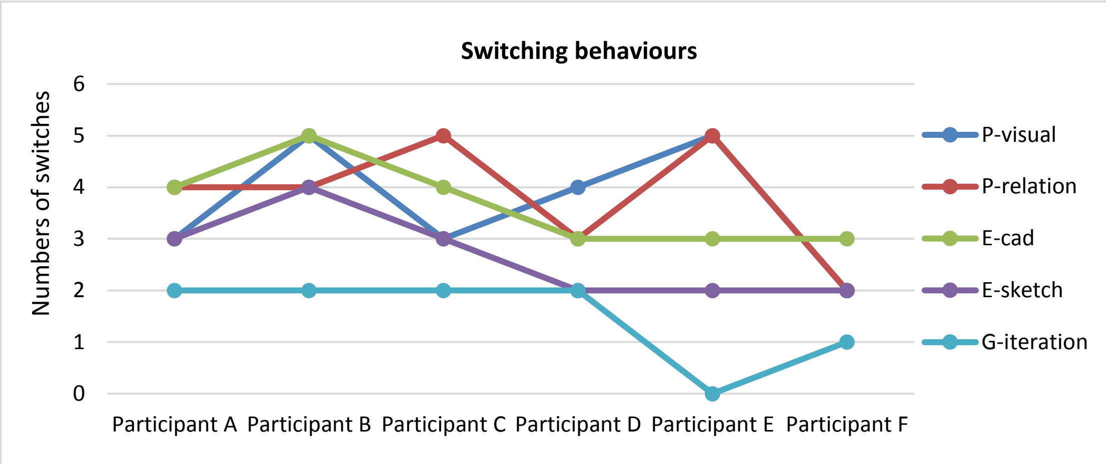
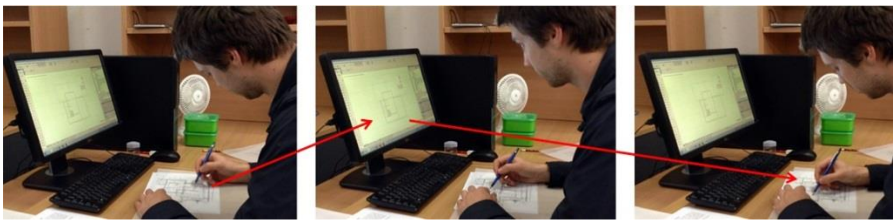
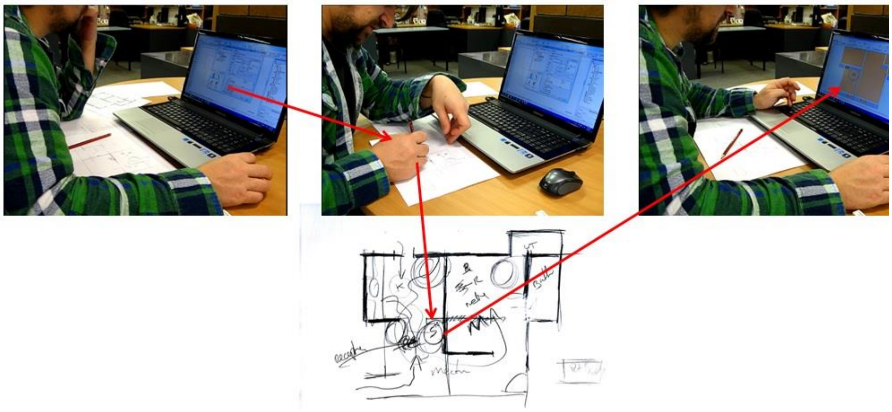


Figure 12. Results of coding switching behaviours for participants.

The perception level refers to the reasoning process of attending to visuospatial features of depicted elements on CAD models (such as a sense of scale between objects) or attending to objects/spaces relationships. The CAD model layout and its visualisation were important visual cues for participants to develop designs in sketching. We refer to eyes' switching as P-visual. The sketches of space arrangements that occurred before using CAD helped implement the object's configuration in CAD modelling and allowed comparisons to be made between sketches and models. P-relation refers to this type of eyes' switching. It happens that after a long time CAD modelling, designers refer to sketches what she / he has already drawn on paper. Or a designer checks a screen to retrieve CAD model information (such as scale, layout) to explore design alternatives during sketching. In this connection, one participant commented 'Personally, I do like to look at 3D views often when modelling to get a good idea of the project rather than sketching in 3D'. Table 14 shows that participants normally use eyes' switching between media to enhance visuospatial ability.

Table 14. Three types of switching behaviours impact on designers' cognition.

Three types of switching behaviours	
Perception level	 The participant's eyes switched between media to obtain a sense of space scale.

Media level	 **Sketching** **CAD modelling** 1. Sketching: After finishing the first-storey CAD models, the participant switched to sketching to quickly explore ideas for the second-storey layout. 2. CAD modelling: An advantage of CAD modelling is that it allows participants to understand different perspectives by rotating or zooming in/out.
Concept level	 The participant found it challenging to locate an appropriate place for a stair using CAD. He therefore switched to sketching to refine and evaluate different locations. Once satisfied, the participant transferred the sketches in CAD so the switching was a bridge, linking the idea development process between media.

The media level referred to in Table 14 relates to exploring interactions between design media and designers. Participants switched from sketching to CAD or from CAD to sketching because the effectiveness of each design medium is different. Sketching allows designers to quickly draw their ideas on paper. These drawings can then be used by designers to generate alternatives. We have called this activity E-sketching. CAD environments offer more detailed and realistic designs, providing designers with superior visual feedback. These CAD drawings are accurately dimensioned and to scale. They help designers evaluate the sketches developed earlier. We refer to this action as E-cad. For example, one participant identified the strengths of sketching as follows:

'It is certainly quicker and easier to sketch an idea than CAD it up. For instance, a light line on the page may just be a quick idea that ends up getting either forgotten or incorporated into the design by the drawing of progressively heavier lines, whereas… trying to do… similar things with construction lines in a CAD model takes longer, is more to draw, needs to be placed in an

actual location (lines are mostly defined by coordinates) and usually needs to be actively deleted to not confuse the resulting design'. (Participant B)

In contrast, another participant said the following about CAD:

'Its strengths are that when one drafts one element, say the location of the wall, a range of other factors are able to be input like wall height, thickness, construction, colour and even cost and more if required... This then means that when one starts drafting the elevation some of the information is already there, and then again, in 3D the form quickly takes shape and can be viewed, checked for element clashes, zoom in and zoom out, and quickly used for perspective view'. (Participant C)

The concept level (Table 14) refers to the development of design goals by focusing on one intention/target (e.g. stair design and arrangement) through multiple switches to achieve the desired goal. This often happens when designers review previous drawings and are not satisfied with the outcomes in CAD models. This motivates designers to switch between media for one intonation of one goal (e.g. stair design or bathroom objects/spaces reconfiguration). As an example, after completion of the ground-level design in CAD, designers switched to sketching to explore alternatives for the first-level design. This refers to single switching. However, a designer may not be satisfied with a stair design in sketches and/or CAD models because the stair may not connect two levels and provide good circulation. The designer would then need to go back and forth focusing on stair design (one intention) to solve this issue. This refers to integrating switching as G-iterations. To illustrate this, one participant said 'I felt I could achieve better results by sketching back and forth to alter in tandem with the CAD models. I believe it will allow greater conceptual freedom and exploration of ideas'. Additional feedback from another participant was that

'When designing around the placement of the stairs I found it helpful to reference the sketches I had done earlier. CAD allowed me to quickly operationalise the location of the stair using the original location (in the sketch) as the frame of reference from which I could easily deviate and modify in CAD'. (Participant F)

In addition, Figure 13 provides an example of design activities using the AMM approach containing three types of design behaviours. From empirical evidence, the period of a creative design was identified in the AMM design process.

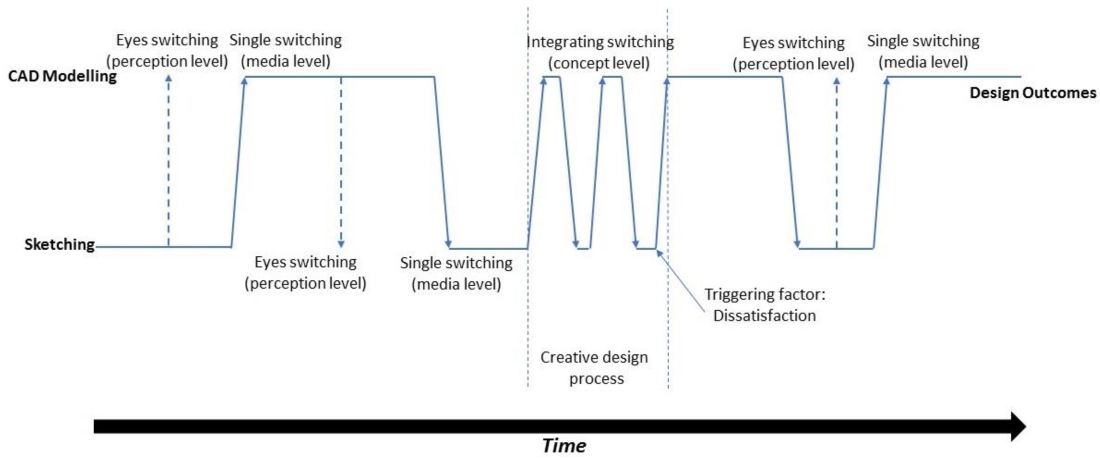


Figure 13. An example of design activities using the AMM design approach.

5. CONCLUSION

This study set out to explore the impact of switching behaviour on designers' cognition. To achieve this, a protocol study was conducted to collect empirical data from eight designers using the SMM approach and the AMM approach. Two types of coding schemes (process-oriented and content-oriented) capable of examining the roles of sketching and CAD modelling (in both SMM and AMM) and switching behaviours (in the AMM) were developed. Applying the research method of protocol analysis, the roles sketching and CAD modelling using both approaches were identified. Through a series of data analyses, three main findings have been identified:

(1) the commonalities of using the SMM and AMM approaches: Three design briefs with similar challenges were randomly assigned to eight designers through a protocol study. The aggregated data collected from this study were coded and those relating to sketching only accounted for under one-third of total codes in both SMM (78/245) and AMM (80/275) sessions. This was because designers spent most of time working on the CAD models to meet design requirements. The data were analysed using the FBS coding scheme, revealing that the roles of sketching and CAD modelling were very similar for these two approaches during the design processes. Three assessments using the FBS coding scheme were design issue distributions, problem-solution (P-S) index and design process distributions.

(2) designers' reflections about the two approaches: Designers' reflections about the two approaches were very different. They experienced several difficulties using the SMM approach. For example, a participant said: *'It did present some difficulties. As a designer one naturally reflects through interacting with representational media. Initially sketching helps recall and store ideas. Today, as a designer I often sketch, and a lot. The integration with computers and CAD in particular has not been difficult but one establishes workflows that accommodate the new tools such as CAD with sketching and ideation. By isolating the workflow, it made it difficult (to) quickly switch between ideas and rapidly formulate responses'.* There were also some drawbacks of using CAD modelling after sketching (without switching) is primarily documentation. The SMM approach is not a

natural design behaviour as it slows down the design process. Most designers preferred to sketch ideas on paper and test them in a CAD environment. If they experienced design problems using CAD, they sketched alternate ideas and then tested them using CAD. In the SMM exercises, participants had to resolve all the problems they encountered on the screen without reverting to sketches.

In addition, participants identified several benefits during the AMM design process as follows: *'I feel that when ideas are more conceptual it is faster and easier to sketch, and when ideas are more developed it is faster and easier to use CAD. I feel that sketching informs the development of an idea that is then drawn in CAD for evaluation, which informs the next round of sketching and so on…. Each medium is useful for different purposes and by using both methods we can get the benefits of speed and conceptual thinking with sketching and also the accuracy and technical resolution of CAD'.* The results of using the AMM approach confirmed that the role of switching behaviour is to make use of the advantages from both media, and to use each one to counter the weaknesses of the other. For instance, sketching allows designs to be prepared quickly but is not accurate, while CAD modelling is an accurate means of preparing documentation but is a slow method of preparing designs. Mixed media allows a designer be fast and accurate, which supports Ibrahim and Rahimian's (2011) and Sachse et al.'s (2001) findings. It is usually faster to brainstorm ideas using sketching, and then easier to change these designs using CAD to see if the ideas work with accurate dimensions. Furthermore, 3D modelling allows changes to be visualised almost instantly.

(3) impact of switching behaviour on design cognition: The results of this study show that switching behaviours supported designers' perceptions, media and concept levels during their design activities. This fits the concept of the 'right tool-right time' (Do, 2005: 396). The **perception level** refers to the reasoning process of attending to visuospatial features of depicted elements on CAD models (such as a sense of scale between objects) or attending to objects/spaces relationships. The CAD model layout and its visualisation were important visual cues for participants and assist them in developing designs in sketching. The sketches of space arrangements produced before using CAD helped implement the object's configuration in CAD and allowed comparisons to be made between sketches and models. The **media level** relates to exploring interactions between design media and designers. Participants switched from sketching to CAD or from CAD to sketching because the effectiveness of each design medium is different. Sketching allows designers to quickly draw their ideas on paper. These drawings can then be used to generate alternatives. CAD environments offer more detailed and realistic designs, providing designers with superior visual feedback. These CAD drawings are accurately dimensioned and to scale. They help designers evaluate the sketches developed earlier. The **concept level** refers to the development of design goals by focusing on one intention/target (e.g. stair design and arrangement) through multiple switches to achieve the desired goal. This often happens when designers review previous drawings and are not satisfied with the outcomes in CAD models. This motivates them to switch between

media for one iteration of one goal (e.g. stair design or bathroom objects/spaces reconfiguration). As an example, after completion of the ground-level design in CAD, designers switched to sketching to explore alternatives for the first-level design. However, a designer may not be satisfied with a stair design in sketches and/or CAD models because the stair may not connect two levels and provide good circulation. The designer would then need to go back and forth focusing on stair design to solve this issue. This confirmed that dissatisfaction is the triggering factor for designers to switch between media.

Although the development of new design media/software could help a designer accomplish a desired outcome, s/he may need training to manipulate such new design media. The framework of this research is to purpose a new way of using available design media (i.e. sketching and CAD modelling) involving switching behaviours to offer the advantages of mixed media design environments. The implications of this study include design practice and design education. One of the contributions from this study is to explore ideal approaches of using mixed media.

References

Akin, Ö. and Moustapha H. (2003). Strategic use of representation in architectural massing. *Design Studies*, 25(1).

Ball, L. J., Ormerod, T. C. and Morley, N. J. (2004). Spontaneous analogising in engineering design: A comparative analysis of experts and novices. *Design Studies*, 25, 495-508.

Bilda, Z. and Gero, J. S. (2007). The impact of working memory limitations on the conceptual design process. *Design Studies* **28**(4), 343-367.

Bilda, Z., Gero, J. S. and Purcell, T. (2006). To sketch or not to sketch? That is the question, *Design Studies* **27**(5), 587-613.

Bouchlaghem, D., Shang, H., Whyte, J. and Ganah, A. (2005). Visualisation in architecture, engineering and construction (AEC). *Automation in Construction* 14(3) 287-295.

Chen, Z. R. (2007). How to improve creativity: Can designers improve their design creativity by using conventional and digital media simultaneously? *CAAD Futures 2007,* Australia.

Dorst, K. (1996). The design problem and its structure. *in* N. Cross, H. Christianns and K. Dorst (eds.), *Analysing Design Activity*, John Wiley & Sons Ltd, Chichester, New York, 17-35.

Dorst, K. and Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies*, 22(2), 425–437.

Dorst, K. and Dijkhuis, J. (1995). Comparing paradigms for describing design activity. *Design Studies*, 16 (2), 261-274.

Do, E. Y. L. (2005). Design sketches and sketch design tools. *Knowledge Based Systems* (18) 383-405.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). The evolution from filebased exchange to building model repositories. BIM Handbook: A guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors (2nd ed.). John Wiley & Sons Inc.

Ericsson, K. A. and Simon, H. A. (1993). *Protocol Analysis: Verbal Reports as Data.* Cambridge, Mass: MIT Press.

Gero, J. S. (1990). Design prototypes: A knowledge representation schema for design. *AI Magazine*, 11(4), 26-36.

Gero. J. S. and McNeill, T. (1998). An approach to the analysis of design protocols. *Research in Engineering Design,* Springer Verlag, London.

Gero, J. S. and Kannengiesser, U. (2004). The situated Function-Behaviour-Structure framework. *Design Studies*, 25(4), 373-391.

Gero, J. S. and Tang, H. (2001). The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of design protocols. *Design Studies*, 19(1), 21-61.

Gero, J. S., Jiang, H. and Williams, C. B. (2012). Does using different concept generation techniques change the design cognition of design students? *ASME IDETC* DETC2012-71165.

Gero, J. S., Kan, J. W. T. and Pourmohamadi, M. (2011). Analysing design protocols: Development of methods and tools. *in* A Chakrabarti (ed), *Research into Design,* Research Publishing, 3-10.

Gross, M. and E. Y., Do. (1996). Ambiguous Intentions: A Paper-Like Interface for Creative Design. *Proceedings of the ACM UIST Conference*, 183-192.

Goldschmidt, G. and Smolkov, G. (2006). Variances in the impact of visual stimuli on design problem solving performance. *Design Studies*, 27(5), 549-569.

Ibrahim, R. and Rahimian, F. P. (2011). Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction*, 19(8), 978-987.

Jiang, H, Gero, J. S. and Yen, C. C. (2014). Exploring designing styles using problem-solution indexes. *in* JS Gero (ed), *Design Computing and Cognition'12,* Springer, pp. 85-101.

Kan, J. W. T. and Gero, J. S. (2008). Acquiring information from linkography in protocol studies of designing. *Design Studies*, 29(4), 315-337.

Kim, M. J. and Maher, M. L. (2008). The impact of tangible user interfaces on spatial cognition during collaborative design. *Design Studies,* 29(3), 222-253.

Lawson, B. R. (2002) CAD and creativity: Does the computer really help? *Leonardo*, 35(3), 327-331.

Lin, C. Y. (2001). A digital procedure of building construction. *in* Gero, J., Chase, S. and Rosenman, M. (eds), CAADRIA2001, Key Centre of Design Computing and Cognition, University of Sydney, 459-468.

Linstone, H. A. and Turoff, M. (1975). *The Delphi Method: Techniques and Applications.* Addison-Wesley, Reading Massachusetts.

Maher, M. L., Poon, J. and Boulanger, S. (1996). Formalising design exploration as co-Evolution: A combined gene approach. *Advances in Formal Design Methods for CAD*, (ed.) John S. Gero, Chapman & Hall.

Maher, M. L. and Tang, H. H. (2003). Coevolution as a computational and cognitive model of design. *Research in Engineering Design,* 14(1), 47–63.

Newell, A. (1990). *Unified Theories of Cognition*. Cambridge, Mass: Harvard University Press.

Oxman, R. (2006). Theory and design in the first digital age, *Design Studies*, 27(3), 229-265.

Rahimian, R. F., Ibrahim, R. and Jaffar, F. Z. (2008). Feasibility study on developing 3D sketching in virtual reality (VR) environment. *ALAM CIPTA, Int. J. Susta. Trop. Des. Res. Pract*, 3, 60-78.

Salman, H. S., Laing, R. and Conniff, A. (2014). The impact of computer aided architectural design programs on conceptual design in educational context. *Design Studies*, 35 (4), 412-439.

Sachse, P., Leinert, S. and Hacker, W. (2001). Designing with computer and sketches, *Swiss Journal of Psychology*, 60(2), 65-72.

Suwa, M., Purcell, T. and Gero, J. (1998). Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies,* 19, 455-483.

Suwa, M. and Tversky, B. (2001). How do designers shift their focus of attention in their own sketches? *In* Anderson, M., Meyer, B. and Olivier, P. (eds.) *Diagrammatic Reasoning and Representation*, Berlin: Springer, 241-260.

Tang, H. H., Lee, Y. Y. and Gero, J. S. (2011). Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function-behaviour-structure coding scheme. *Design Studies,* 32(1), 1-29.

Van Someren, M. W., Barnard, Y. F. and Sandberth, J. A. C. (1994). The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes. London: Academic Press.

Williams, C. B., Lee, Y., Gero, J. S. and Paretti, M. (2013). Exploring the effect of the design prompt on students' design cognition, *ASME IDETC2013* DETC2013–13557.

Won, P. H. (2001). The comparison between visual thinking using computer and conventional media in the concept generation stages of design. *Automation in Construction,* 10(3), 319-325.

PART III

THIS PART INCLUDES SIX APPENDICES:

A 1. ETHICS APPROVAL DOCUMENT
A 2. PARTICIPANT CONSENT FORMS
A 3. DESIGN BRIEFS
A 4. DESIGN OUTCOMES
A 5. CODING
A 6. CO-AUTHOR STATEMENTS

Appendix 1: Ethics Approval Document

HUMAN RESEARCH ETHICS COMMITTEE

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Progress Report Acknowledgement

To Chief Investigator or Project Supervisor:	**Associate Professor Willy Sher**
Cc Co-investigators / Research Students:	**Professor Mark Taylor** **Mr Yi Teng Shih**
Re Protocol:	**Understanding the changes of designers; behaviours when using mixed media design environments**
Date:	**24-Jan-2014**
Reference No:	**H-2011-0368**

Thank you for submitting your **Annual Progress Report** to the Human Research Ethics Committee (HREC) in relation to the above protocol.

Your report has been accepted and your HREC approval for the above research remains valid. Continuation of this approval will again be subject to the provision of an annual progress report by the due date approximately one year from now.

The timely submission of your report is greatly appreciated.

Human Research Ethics Administration

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Appendix 2: Participant Consent Forms

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Consent Form for the Research Project:
"Understanding the Changes of Designers' Behaviours When Using Mixed Media Design Environments"

Document Version 4; dated 31/7/2013

I agree to participate in the above research project and give my consent freely.

I understand that the project will be conducted as described in the Information Statement, a copy of which I have retained.

I understand I can withdraw from the project at any time and do not have to give any reason for withdrawing.

I consent to:

- Participating in three design environments: CAD modelling, sequential mixed media (SMM), and alternate mixed media (AMM). Three different architectural design tasks with similar complexities will be used, which are a two-floor architectural office design, a two-floor art gallery design and a two-floor dream apartment design. The three design briefs will be assigned randomly before the experiments. The three design tasks will take three hours (one hour for each session) and having them videotaped.
- Participating in a half-hour interview and having it recorded.

I understand that my right to review and edit the transcript of my interview.

I want to request a summary of the results of the research. Yes___ No___

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name: MICHAEL DAWES

Signature: ______________ Date: 15 SEP 2013

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Print Name: Noel Yaxley

Signature: ____________ Date: 23/08/13

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Print Name: JOHN DE BRUYN.

Signature: ______ Date: 14/8/2013.

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I want to request a summary of the results of the research. $\boxed{\text{Yes}}$___ **No**___

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name: IAN WYN OWEN

Signature: ________ Date: 19/08/2013.

Contact details: ian.owen@newcastle.edu.au.

0424 951 610 (MOBILE)

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I understand that my right to review and edit the transcript of my interview.

I want to request a summary of the results of the research. **Yes** X **No**___

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name: NICHOLAS FOULCHER

Signature: ________________ Date: 19/8/13

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I understand I can withdraw from the project at any time and do not have to give any reason for withdrawing.

I consent to:

- Participating in three design environments: CAD modelling, sequential mixed media (SMM), and alternate mixed media (AMM). Three different architectural design tasks with similar complexities will be used, which are a two-floor architectural office design, a two-floor art gallery design and a two-floor dream apartment design. The three design briefs will be assigned randomly before the experiments. The three design tasks will take three hours (one hour for each session) and having them videotaped.
- Participating in a half-hour interview and having it recorded.

I understand that my right to review and edit the transcript of my interview.

I want to request a summary of the results of the research. **Yes___** **No___**

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name: DARIN PHARE

Signature: ______________ Date: 16-AUG-2013

Contact details: c3037641@uon.edu.au

____

Appendix 2: Participant Consent Forms

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

A/Professor Willy Sher
School of Architecture and Built Environment
University of Newcastle,
University Drive, Callaghan,
NSW 2308, Australia
Ph (02) 49215792
Fax (02) 4921 6913
Willy.Sher@newcastle.edu.au

Consent Form for the Research Project:
"Understanding the Changes of Designers' Behaviours When Using Mixed Media Design Environments"

Document Version 4; dated 31/7/2013

I agree to participate in the above research project and give my consent freely.

I understand that the project will be conducted as described in the Information Statement, a copy of which I have retained.

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- Participating in a half-hour interview and having it recorded.

I understand that my right to review and edit the transcript of my interview.

I want to request a summary of the results of the research. **Yes** X **No**___

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name: ANNEMARIE DOSEN

Signature: ______________________ Date: 15/08/13

Contact details: ANNEMARIE.DOSEN@NEWCASTLE.EDU
annie@dasenobst.org

Appendix 2: Participant Consent Forms

THE UNIVERSITY OF
NEWCASTLE
AUSTRALIA

A/Professor Willy Sher
School of Architecture and Built Environment
University of Newcastle,
University Drive, Callaghan,
NSW 2308, Australia
Ph (02) 49215792
Fax (02) 4921 6913
Willy.Sher@newcastle.edu.au

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- Participating in a half-hour interview and having it recorded.

I understand that my right to review and edit the transcript of my interview.

I want to request a summary of the results of the research. **Yes___** **No** ✓

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name: TESSA MORRISON

Signature: ______________ Date: 26/08/13

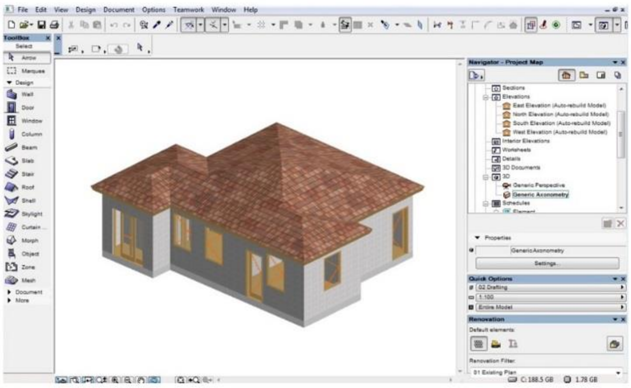
Contact details: 02 4921 5773

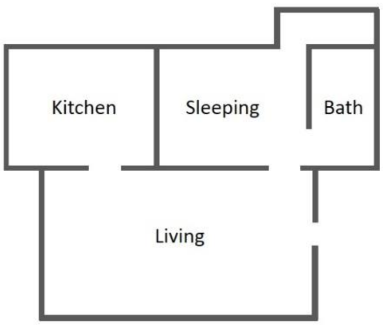
Appendix 3: Design Briefs

Task 1: A Two-floor Art Gallery Design

You are required to design the existing one-floor house into a two-floor art gallery. The gallery is for two salespeople with one manager and will focus on the customers' interaction with the space and its overall aesthetic appeal. The art gallery design must use the provided conversion task but CAD modelling such as walls, doors, etc., can be modified, added or deleted. The gallery should include a reception, big show room, kitchen, bathroom, storage room, hallway, stairs from ground-level and two working rooms with a big balcony on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style, with colour or material; but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models and within the 1-1.5hour timeline.

The experimental CAD model with its 2D layout:



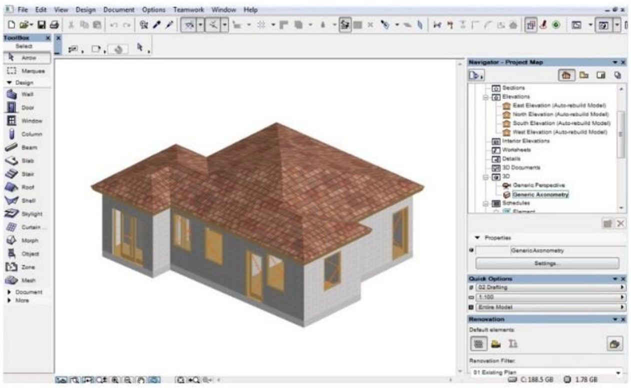


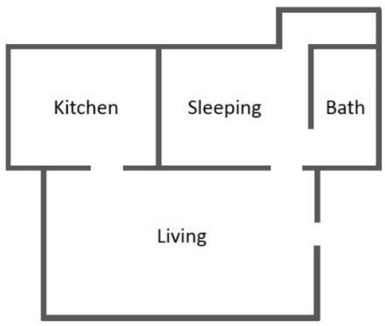
Appendix 3: Design Briefs

Task 2: A Two-floor Architectural Office Design

You are required to design the existing one-floor house into a two-floor architectural office for three architects and one manager. It will need to focus on the architectural designers' interaction with the space and its overall aesthetic appeal. The office design must use the conversion task provided but CAD modelling such as walls, doors, etc., can be modified, added or deleted. This office should include a reception area, meeting room, kitchen, bathroom, garage, hallway, stairs from ground-level and two design rooms, with an open smoking area on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style with colour or material but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models.

The experimental CAD model with its 2D layout:



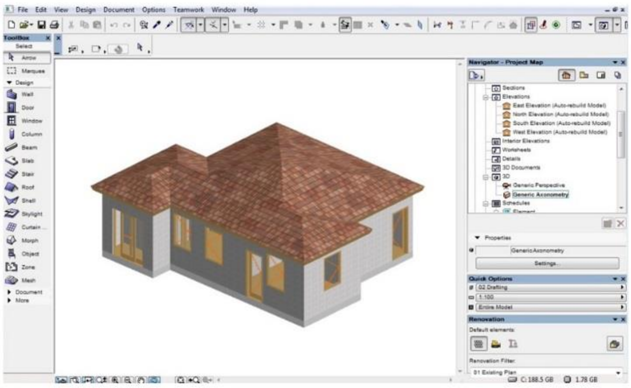


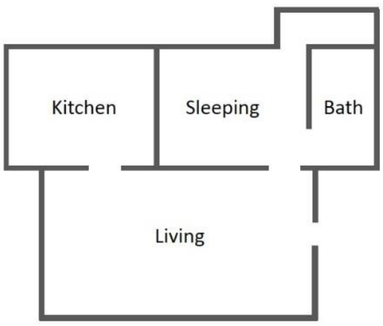
Appendix 3: Design Briefs

Task 3: A Two-floor Dream House Design

You are required to design the existing one-floor house into a two-floor dream house. The apartment is for a young family with one child and will focus on the users' interaction with the space and its overall aesthetic appeal. The apartment design must use the provided extension task but CAD modelling such as walls, doors, etc., can be modified, added or deleted, because the current layout does not satisfy them – for example, the female owner wants more space for the bathroom. This apartment should include a living room, kitchen, bathroom, stairs on at ground-level and two bedrooms with balconies on the first floor. The rooms should have reasonable space with circulation design. At the conceptual design stage, the priority is the overall house style with colour or material but no furniture or structure of building is required. Finally, all participants must, for each design task, satisfy the brief, and clearly represent the design concept in the form of 3D models.

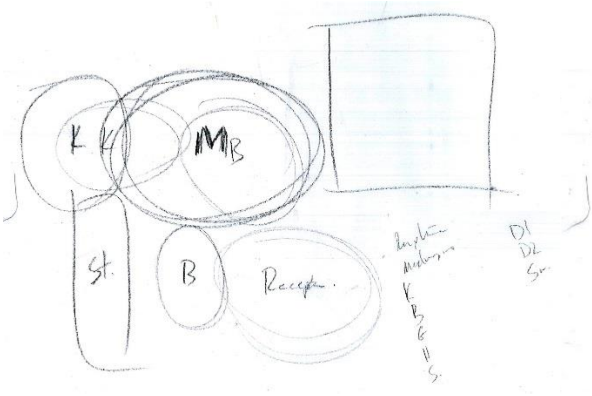
The experimental CAD model with its 2D layout:

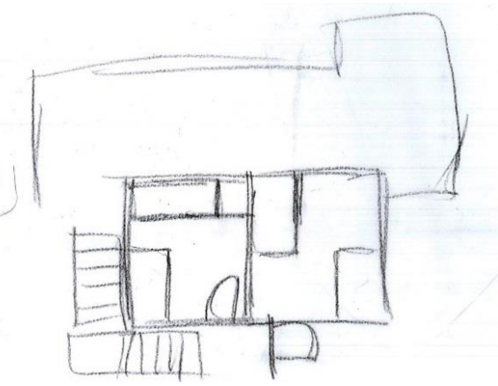


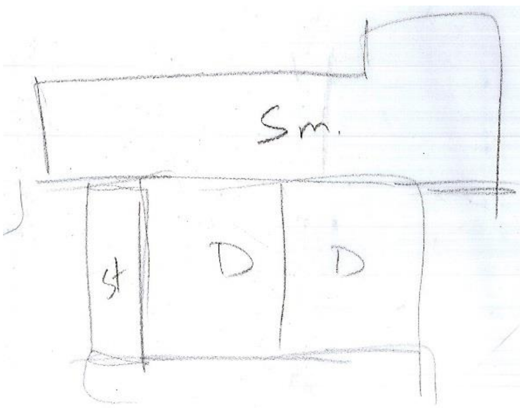


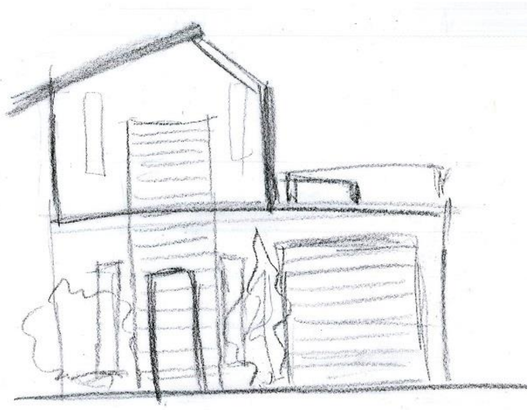
Appendix 4: Design Outcomes

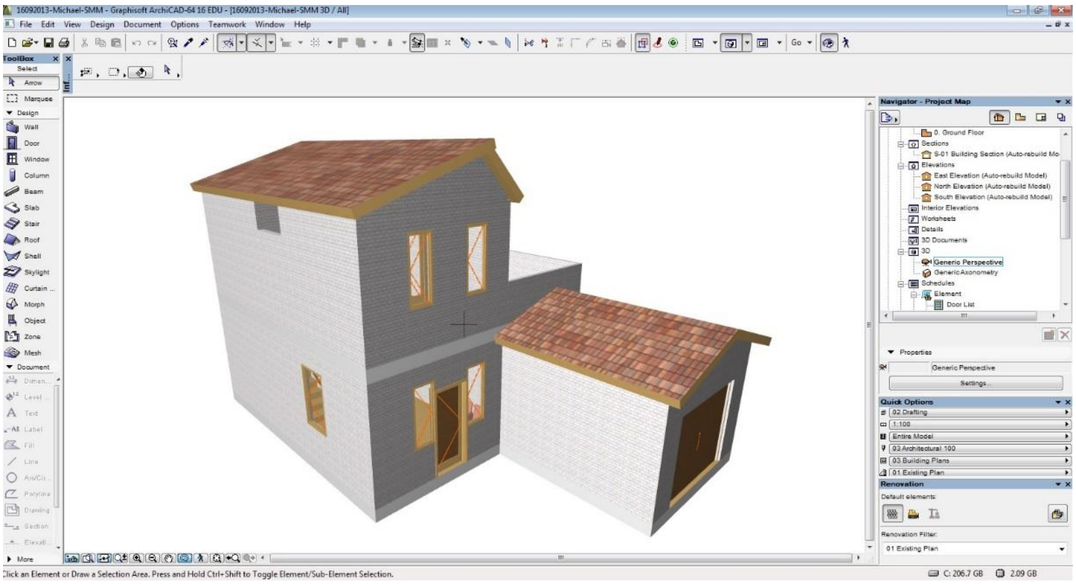
SMM Session: Participant A (Task 2)





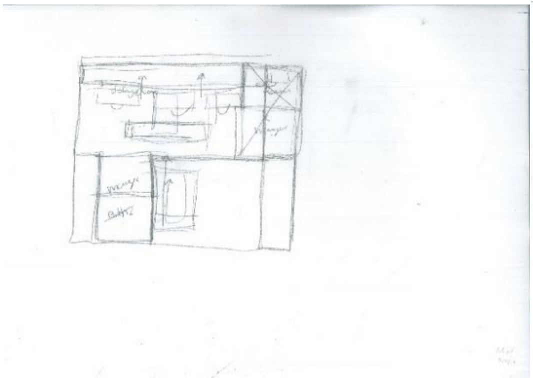


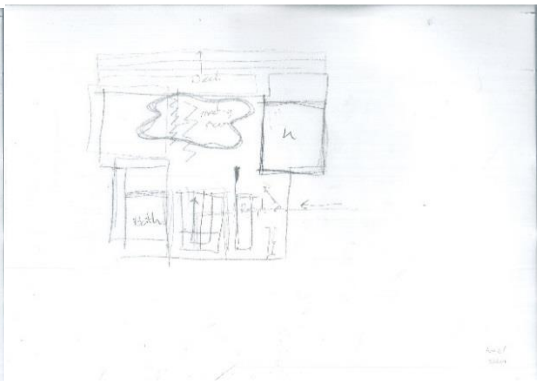


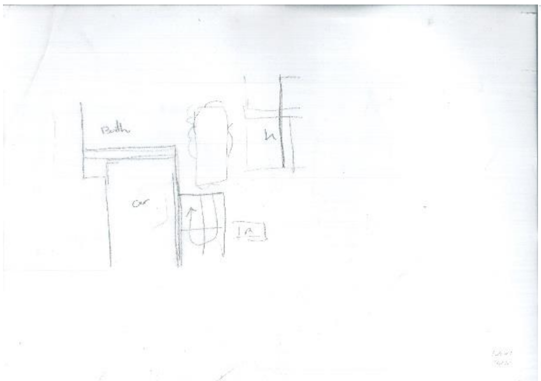


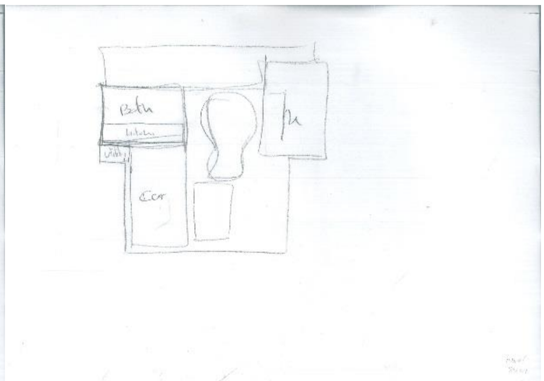
Appendix 4: Design Outcomes

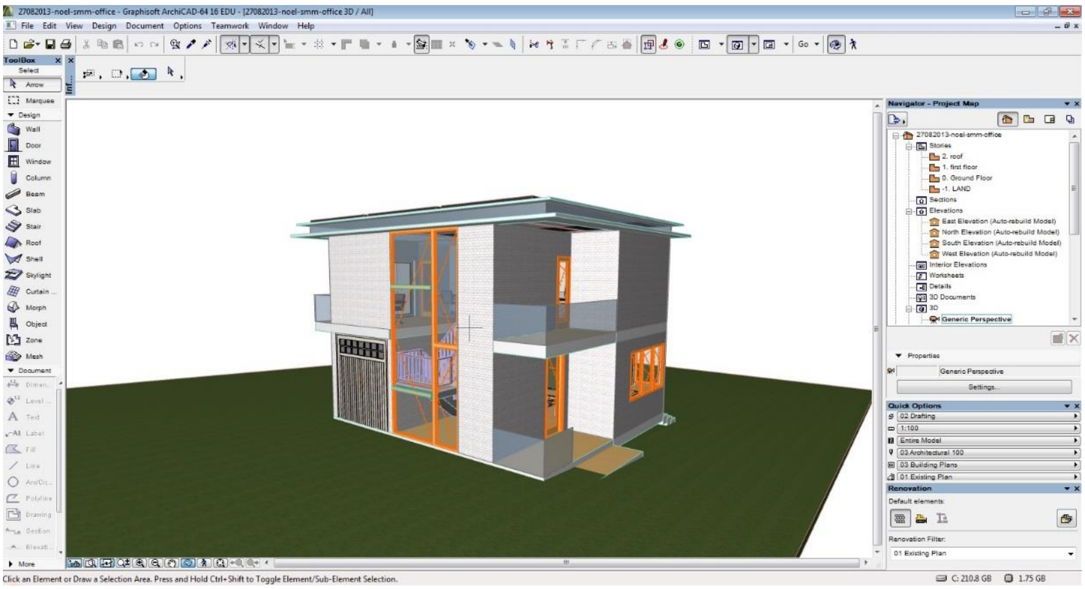
SMM Session: Participant B (Task 2)





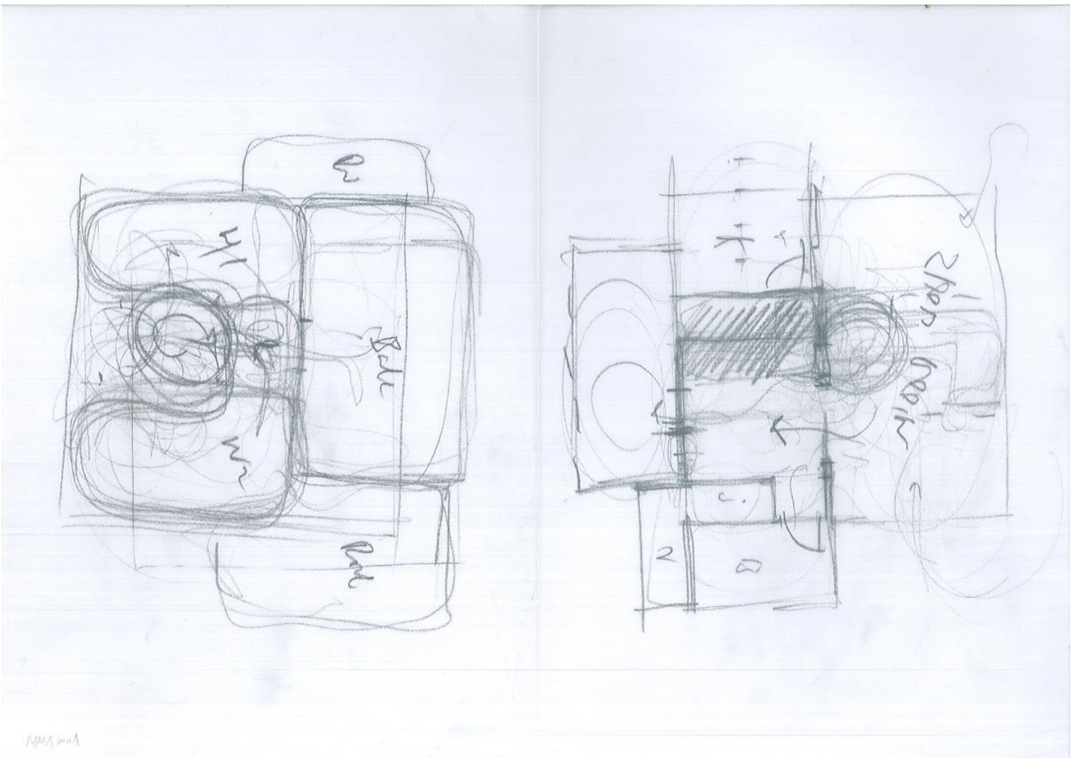


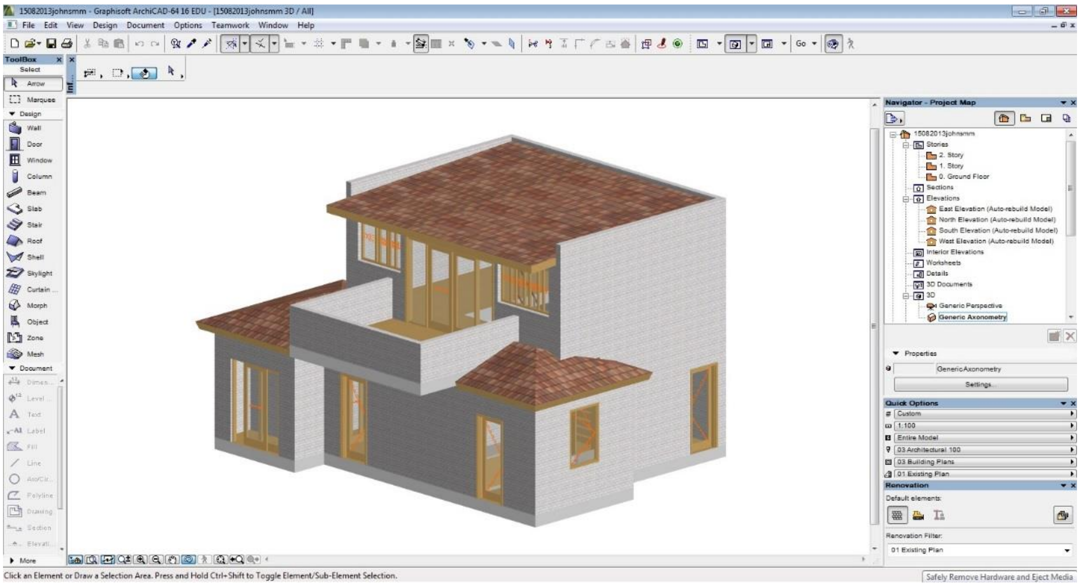




Appendix 4: Design Outcomes

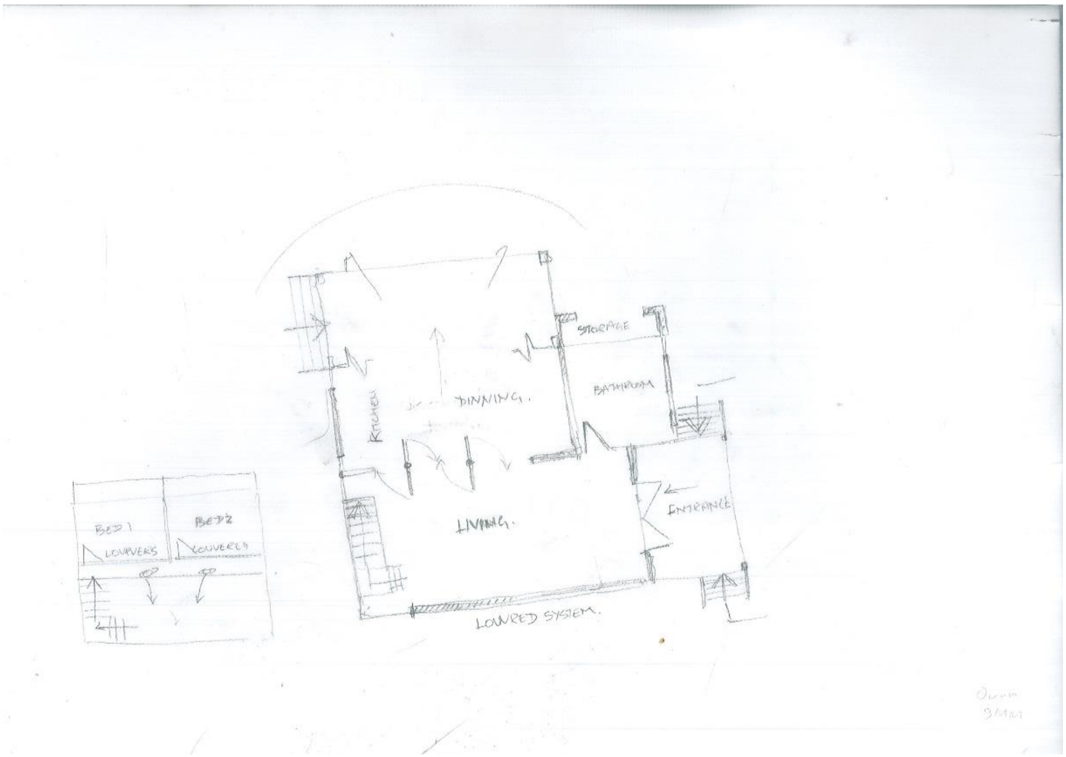
SMM Session: Participant C (Task 1)

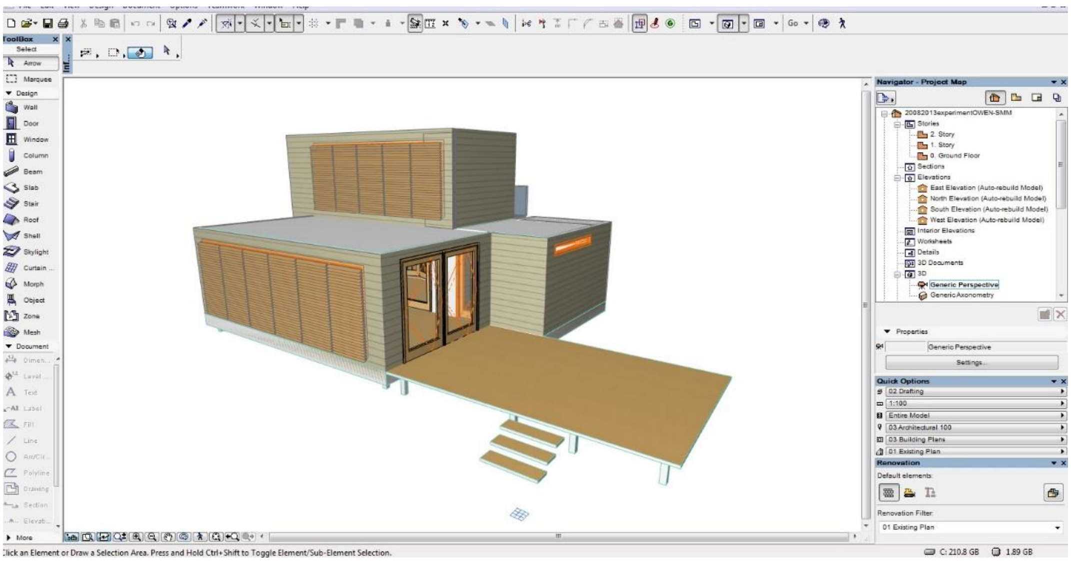




Appendix 4: Design Outcomes

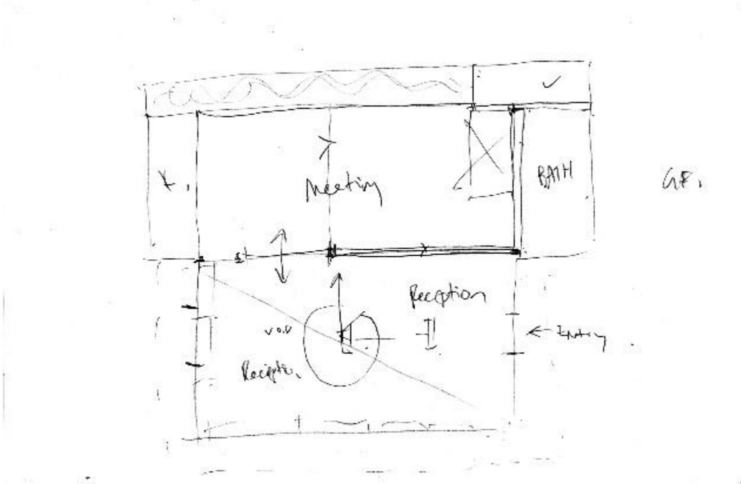
SMM Session: Participant D (Task 3)

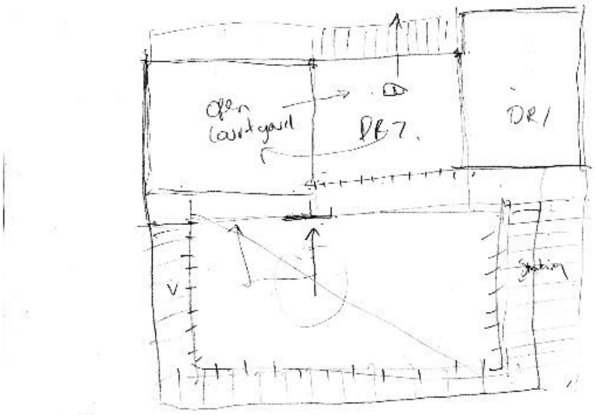


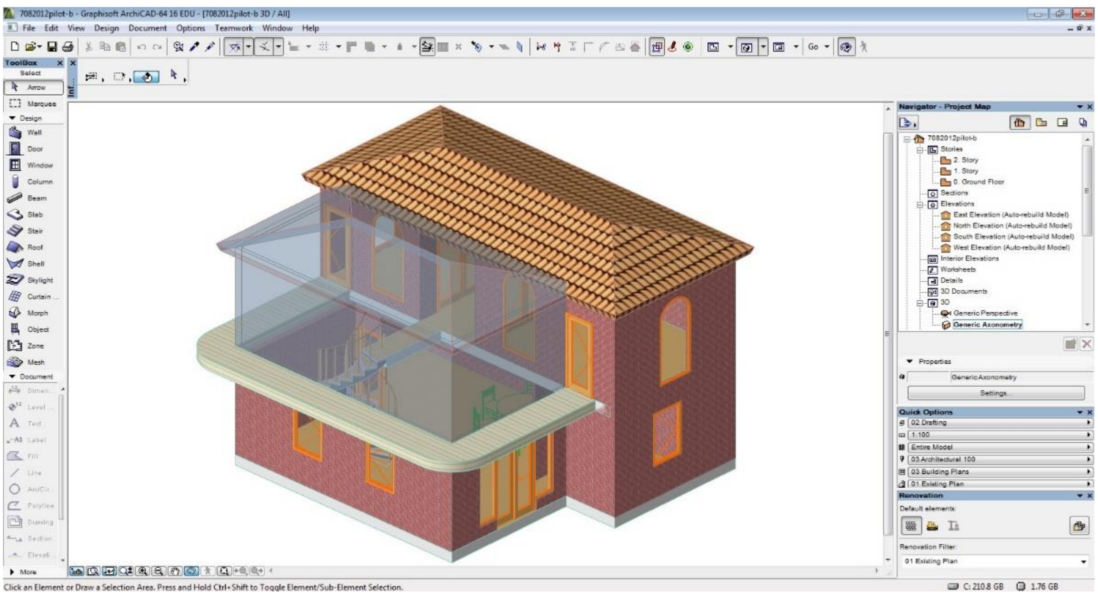


Appendix 4: Design Outcomes

SMM Session: Participant E (Task 2)

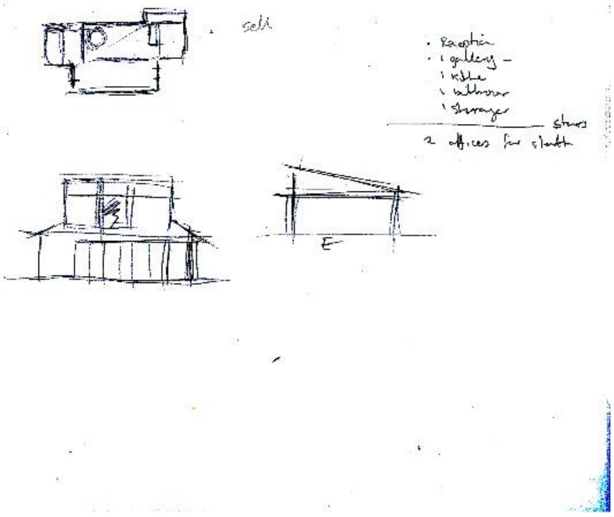


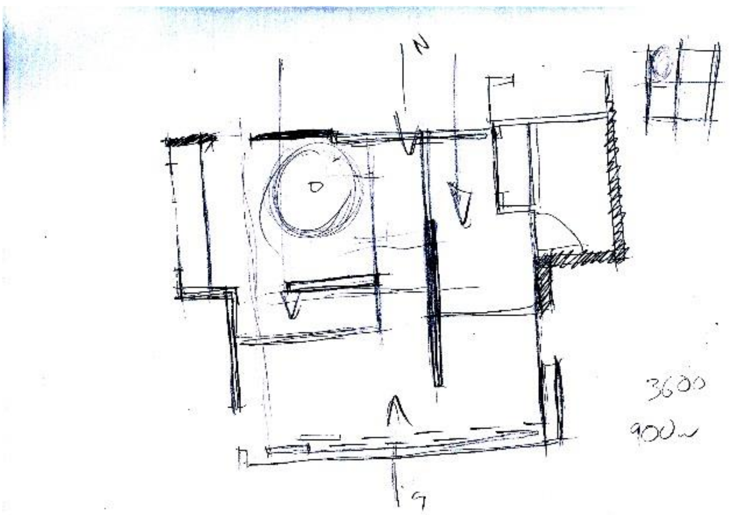


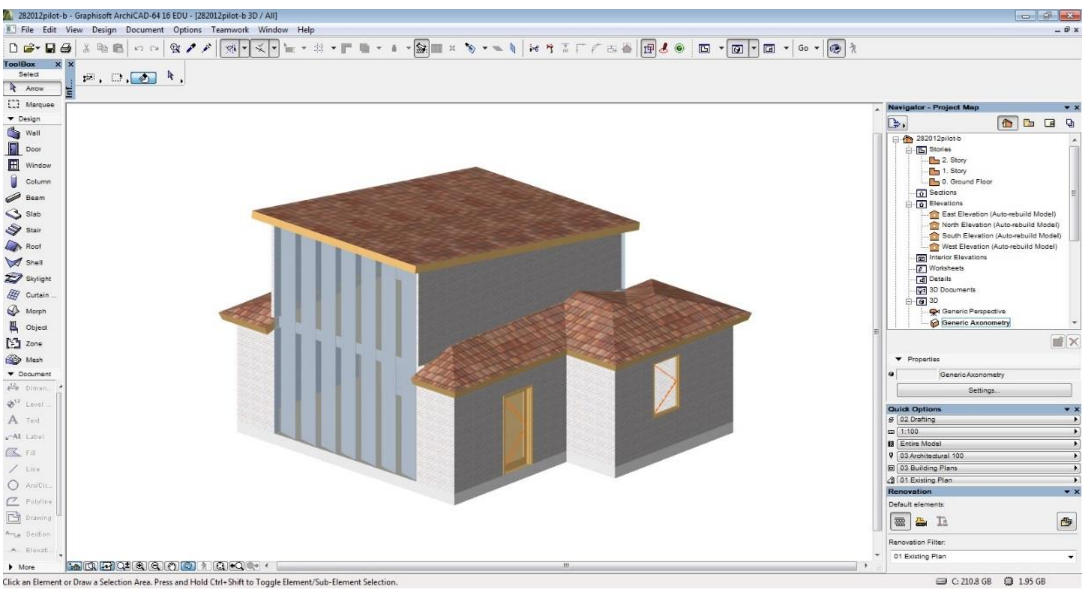


Appendix 4: Design Outcomes

SMM Session: Participant F (Task 1)

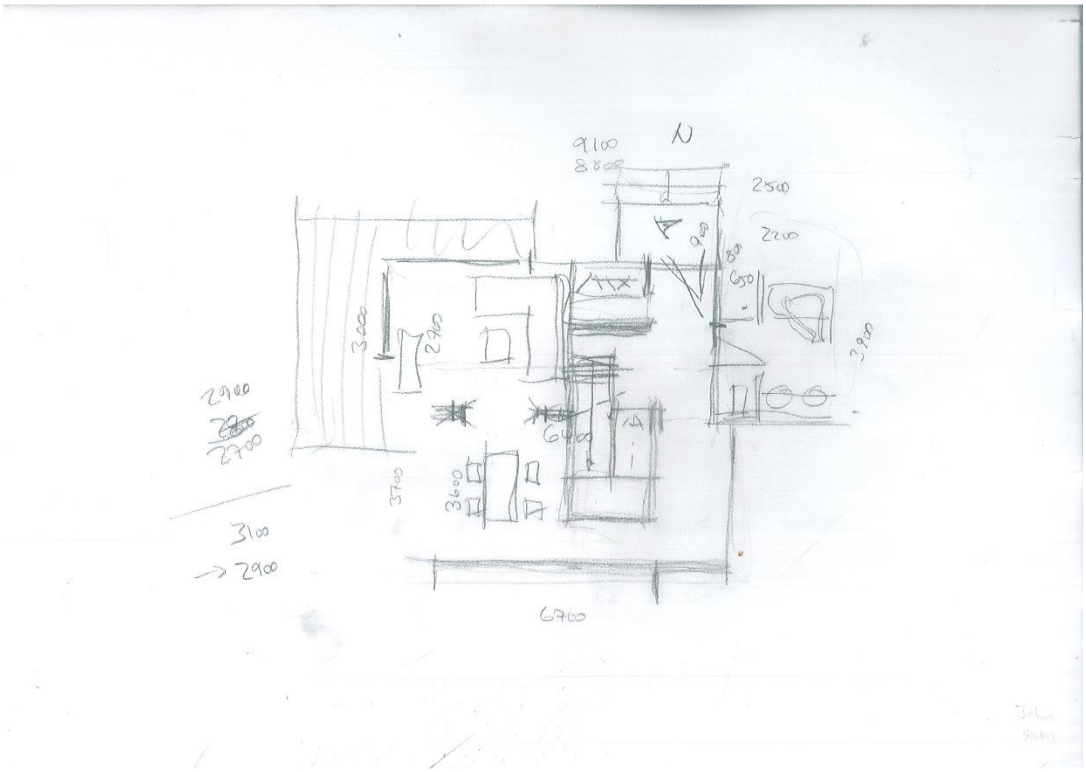


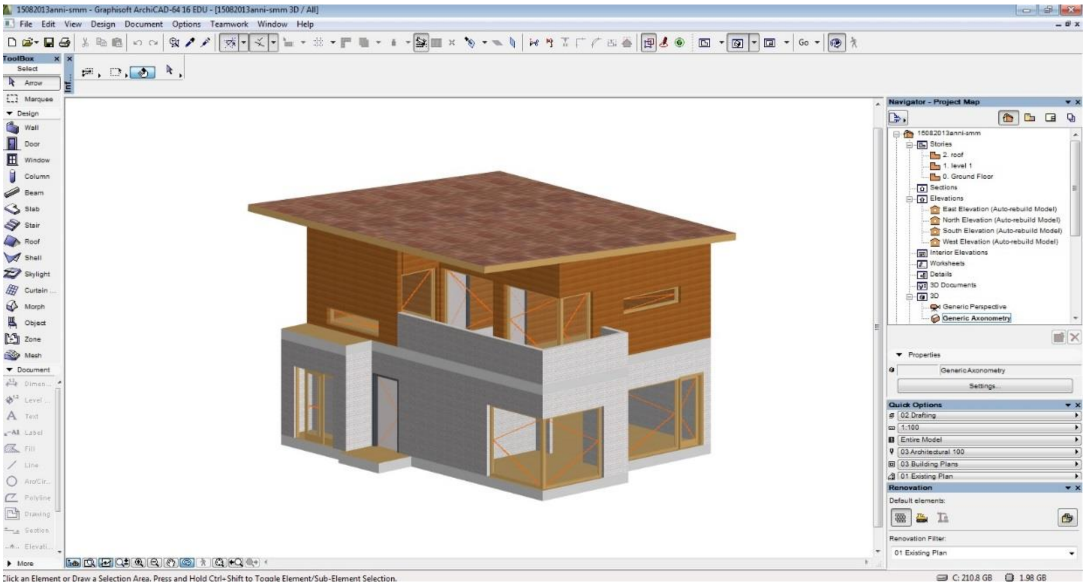




Appendix 4: Design Outcomes

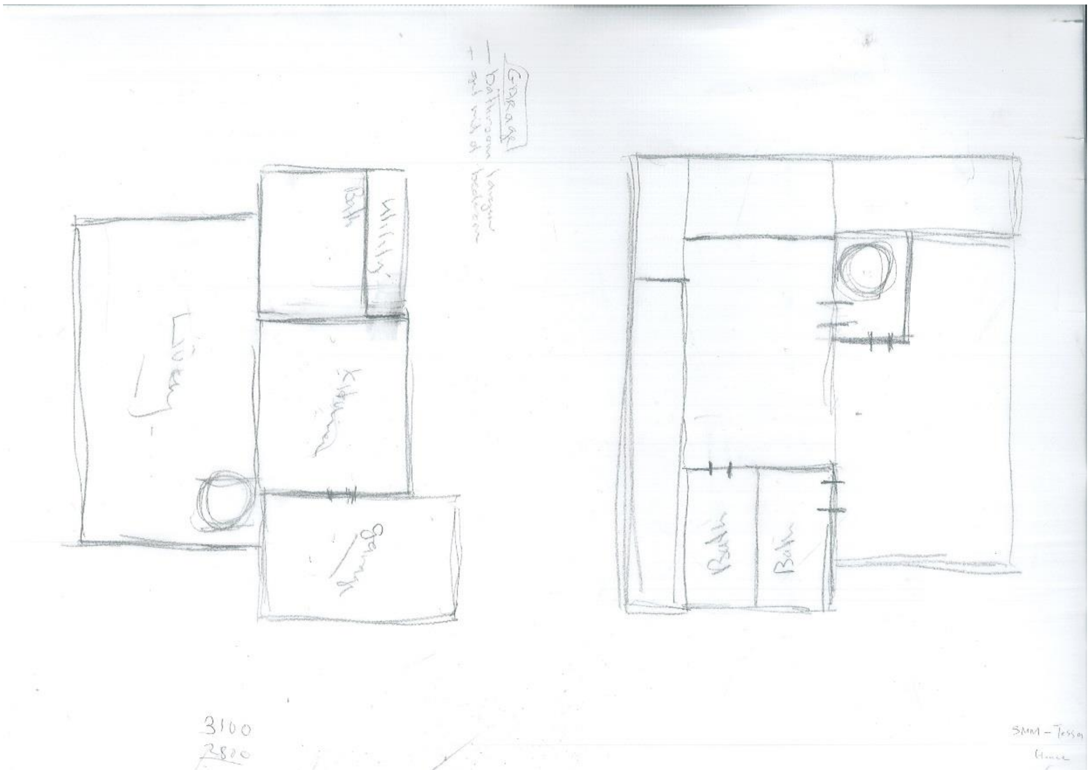
SMM Session: Participant G (Task 3)

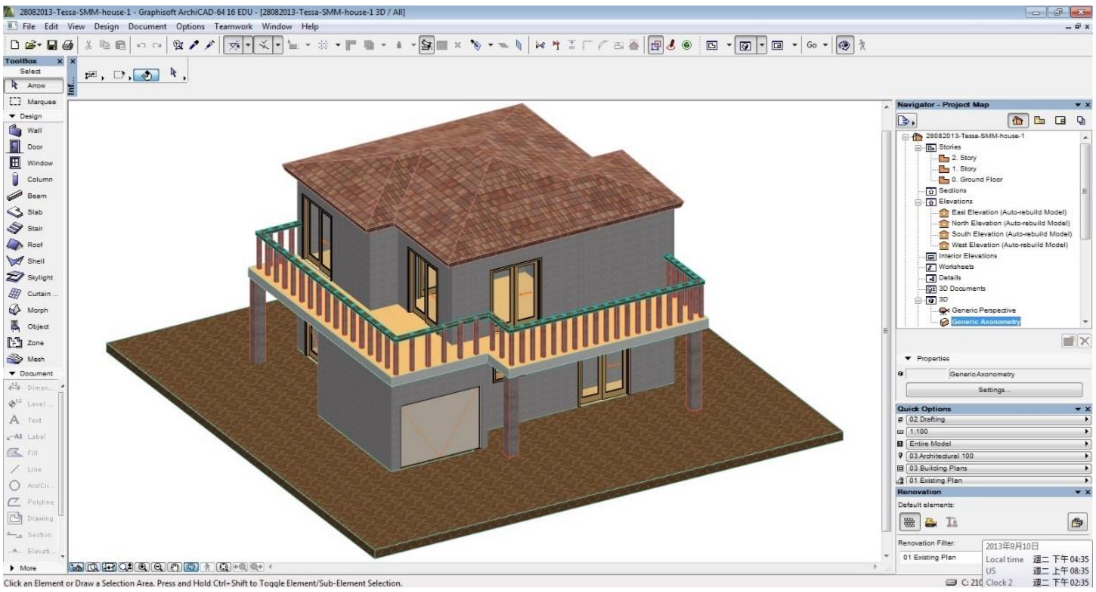




Appendix 4: Design Outcomes

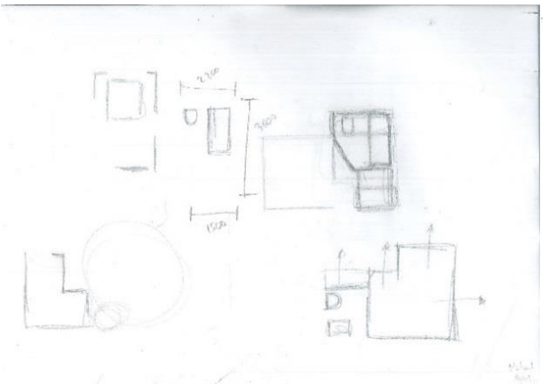
SMM Session: Participant H (Task 3)

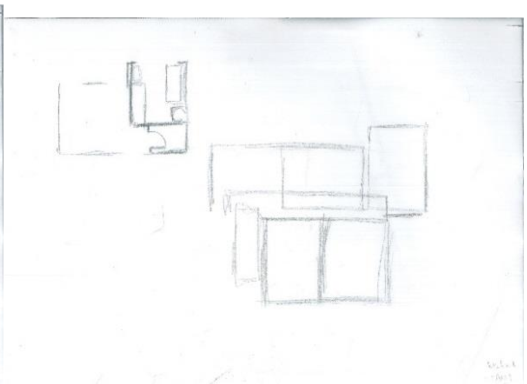


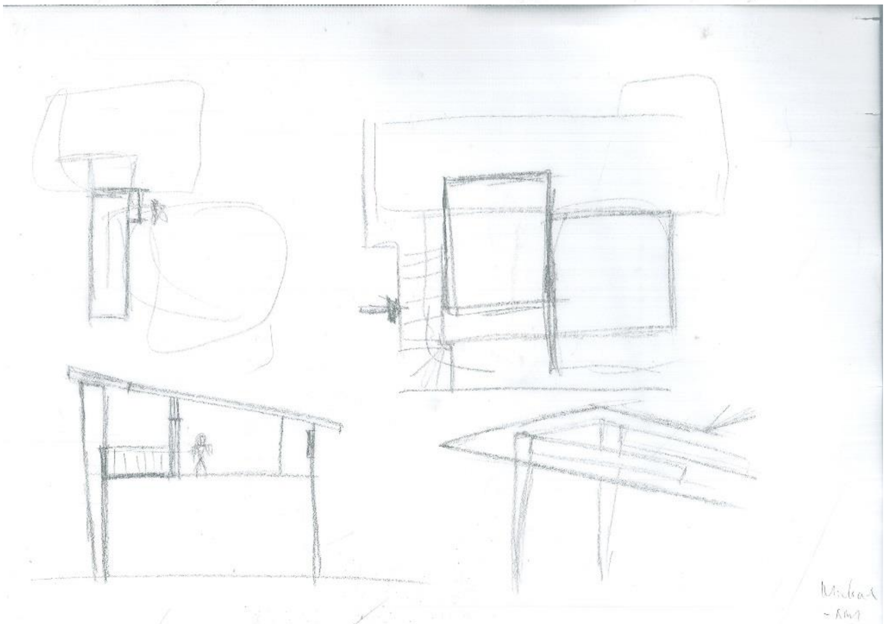


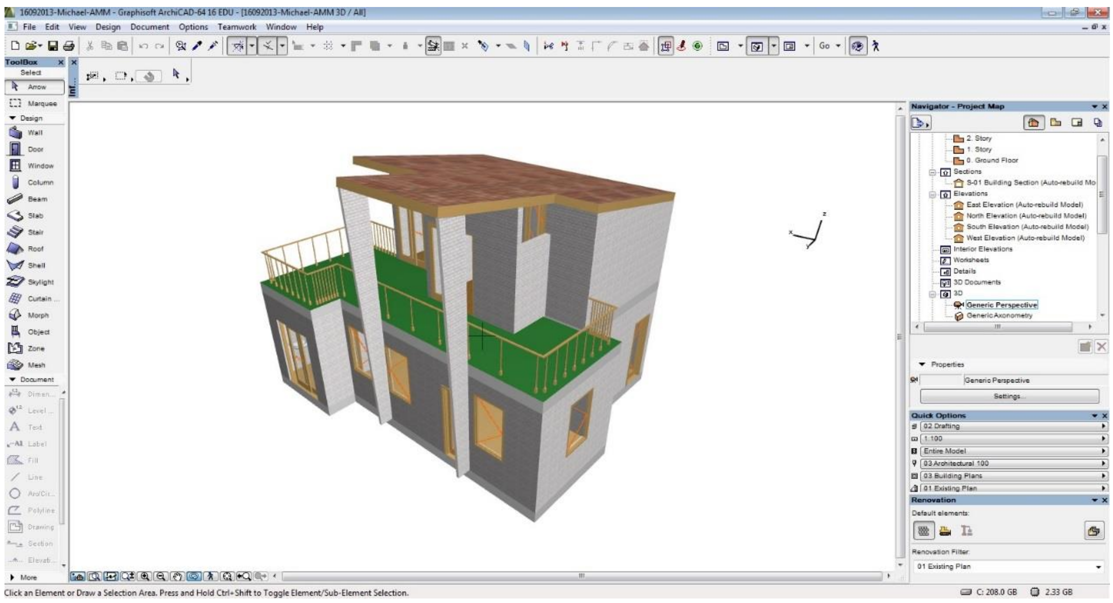
Appendix 4: Design Outcomes

AMM Session: Participant A (Task 3)



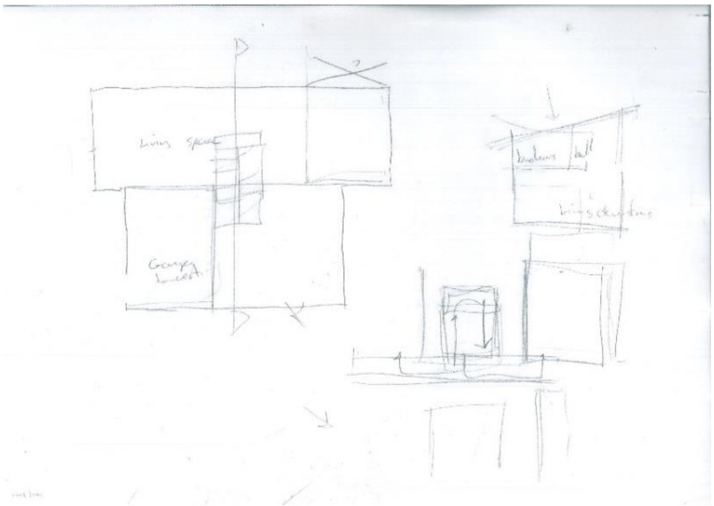


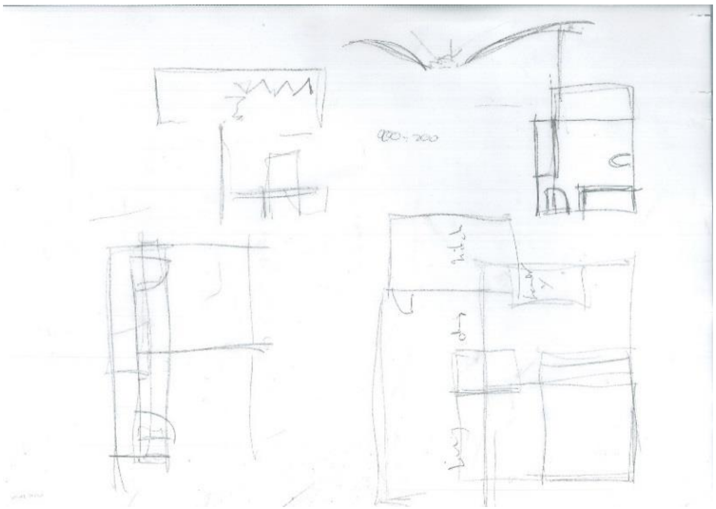


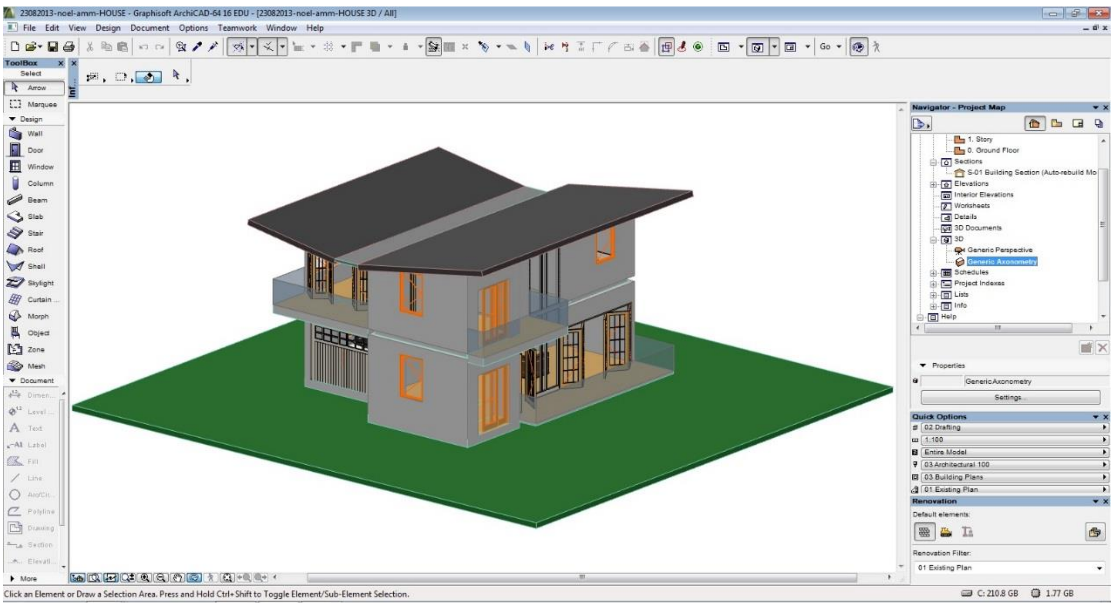


Appendix 4: Design Outcomes

AMM Session: Participant B (Task 3)

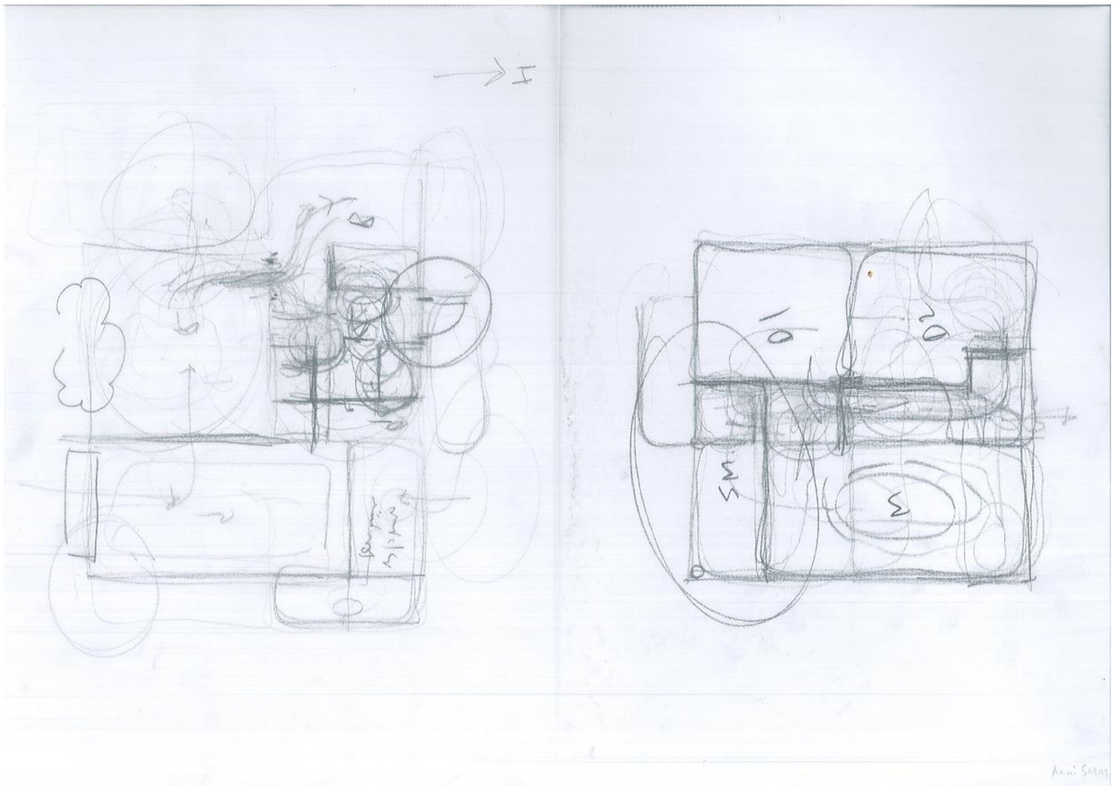


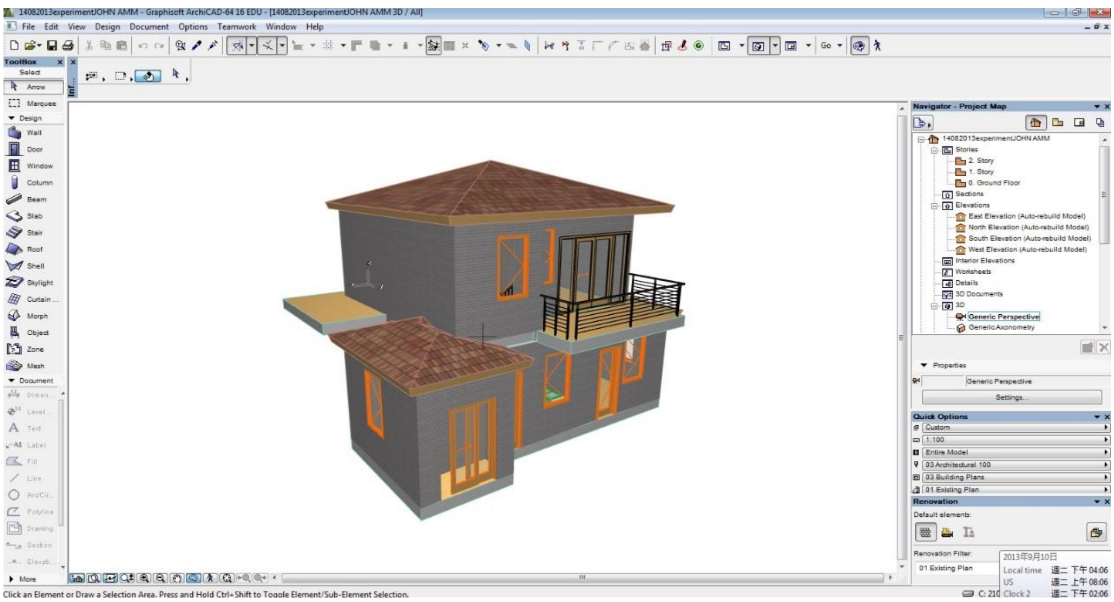




Appendix 4: Design Outcomes

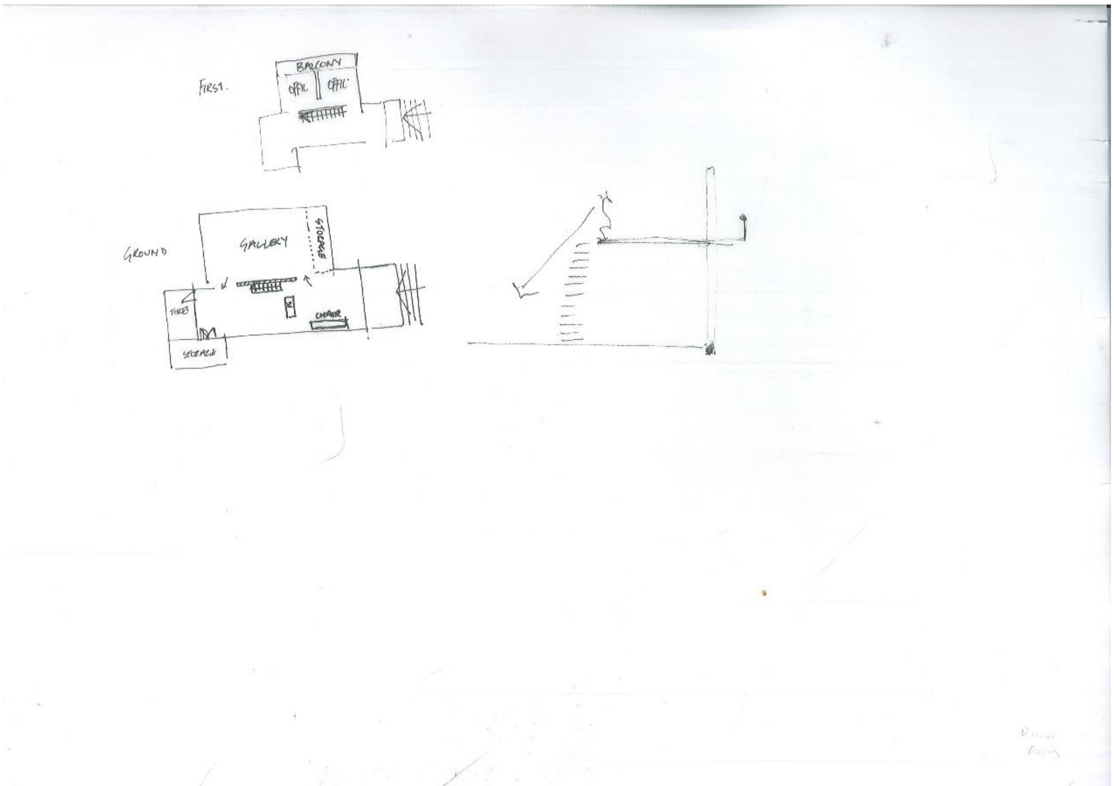
AMM Session: Participant C (Task 2)

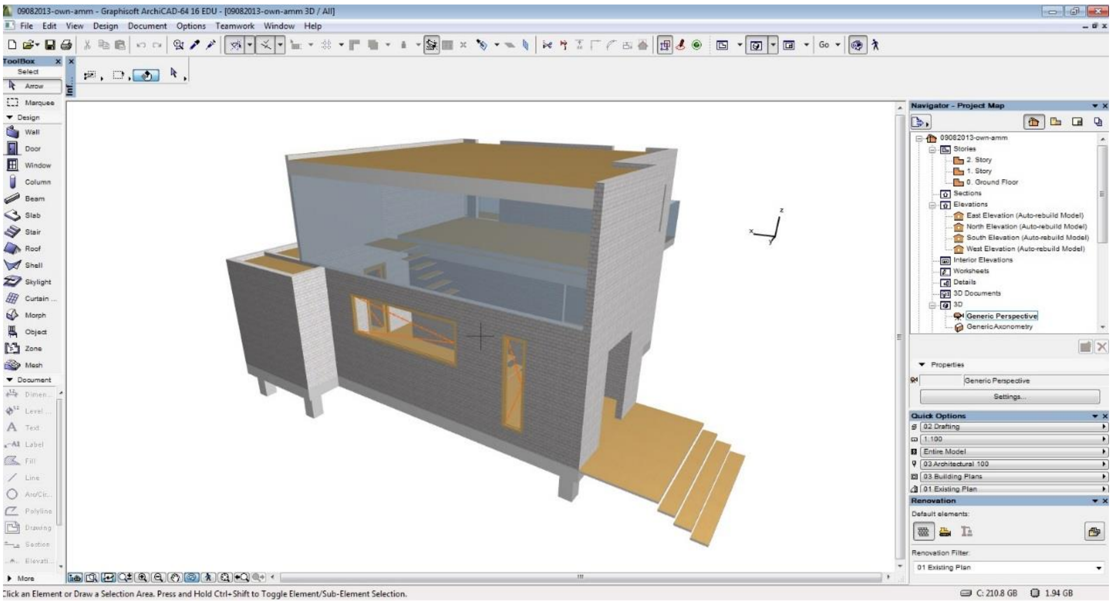




Appendix 4: Design Outcomes

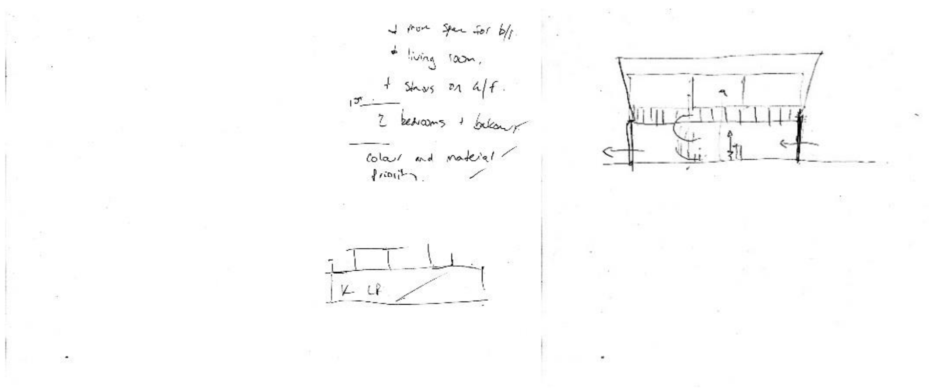
AMM Session: Participant D (Task 1)

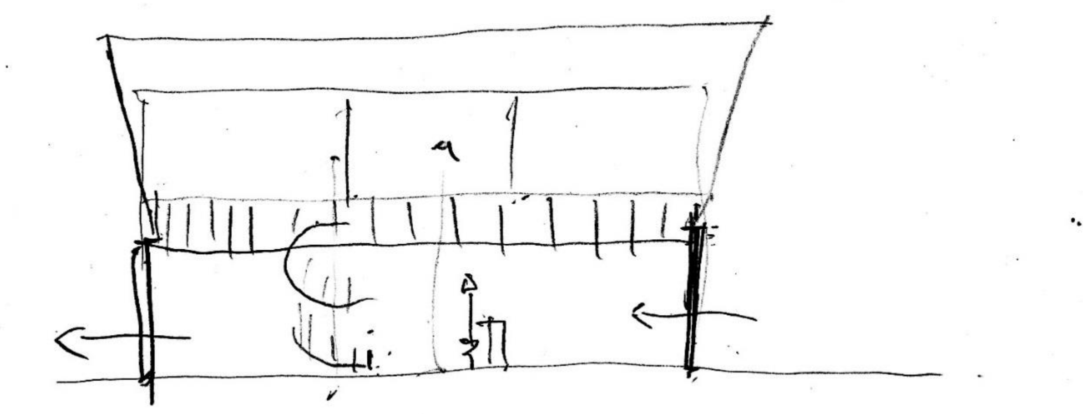


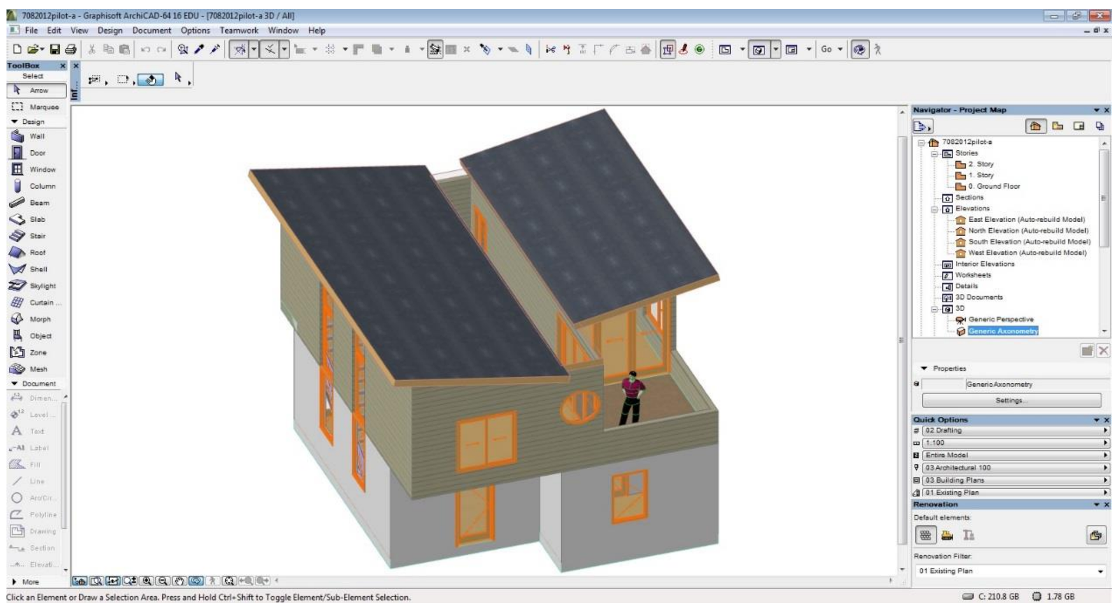


Appendix 4: Design Outcomes

AMM Session: Participant E (Task 3)

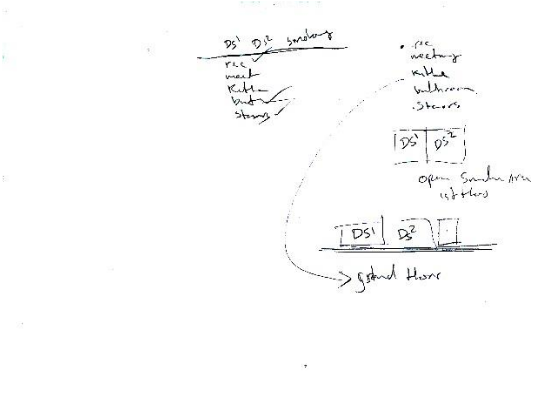


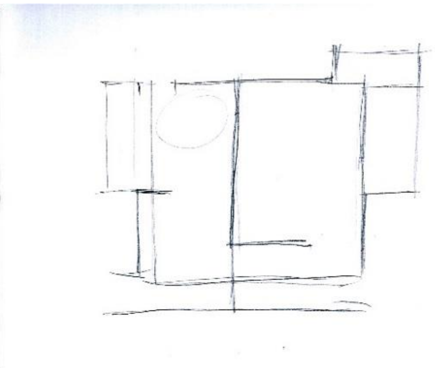


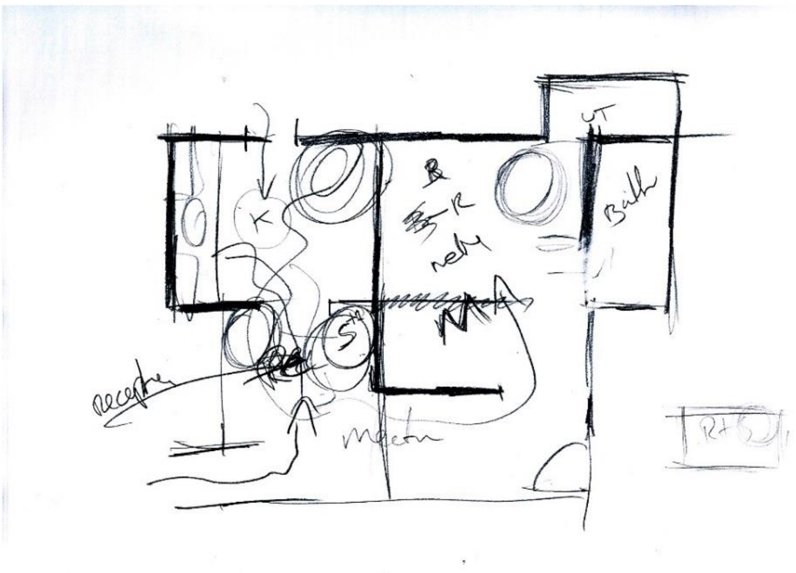


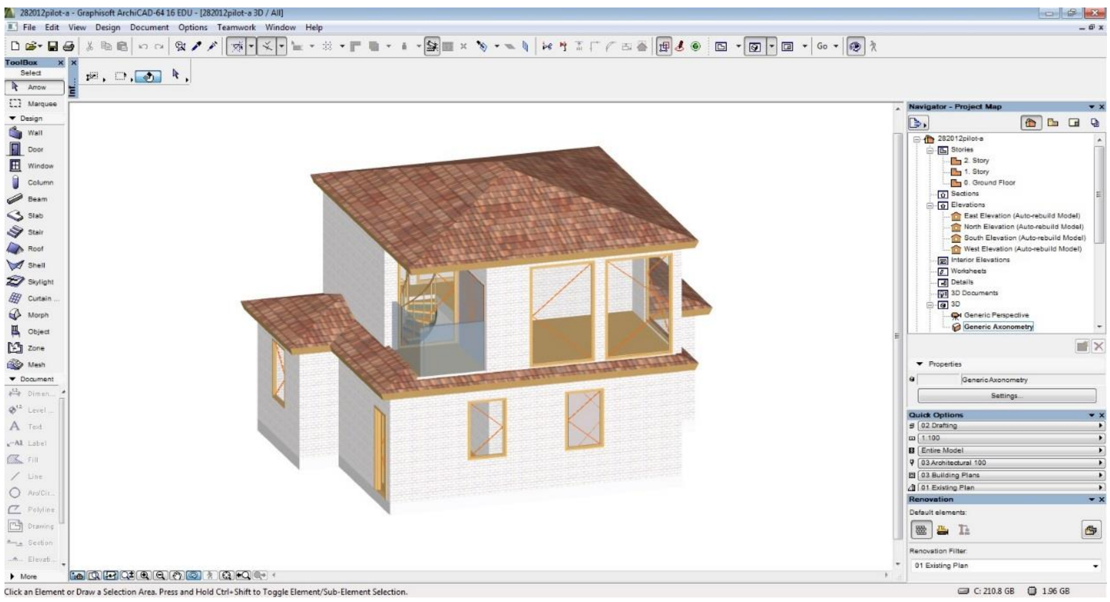
Appendix 4: Design Outcomes

AMM Session: Participant F (Task 2)



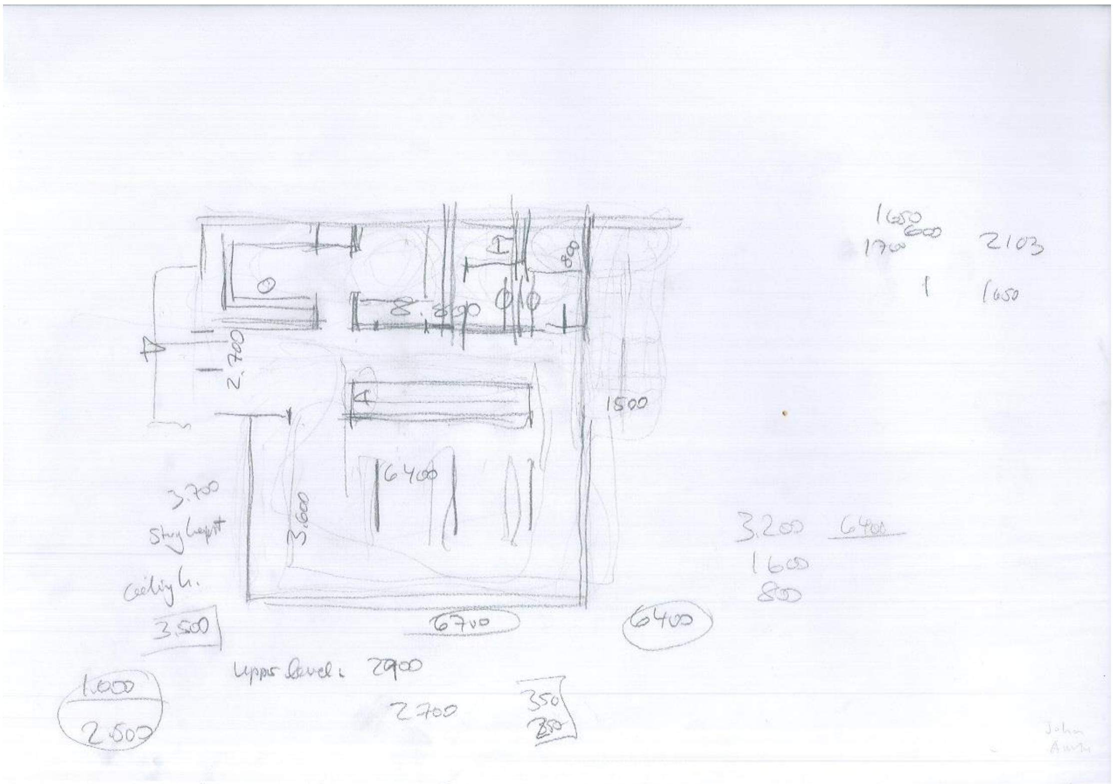


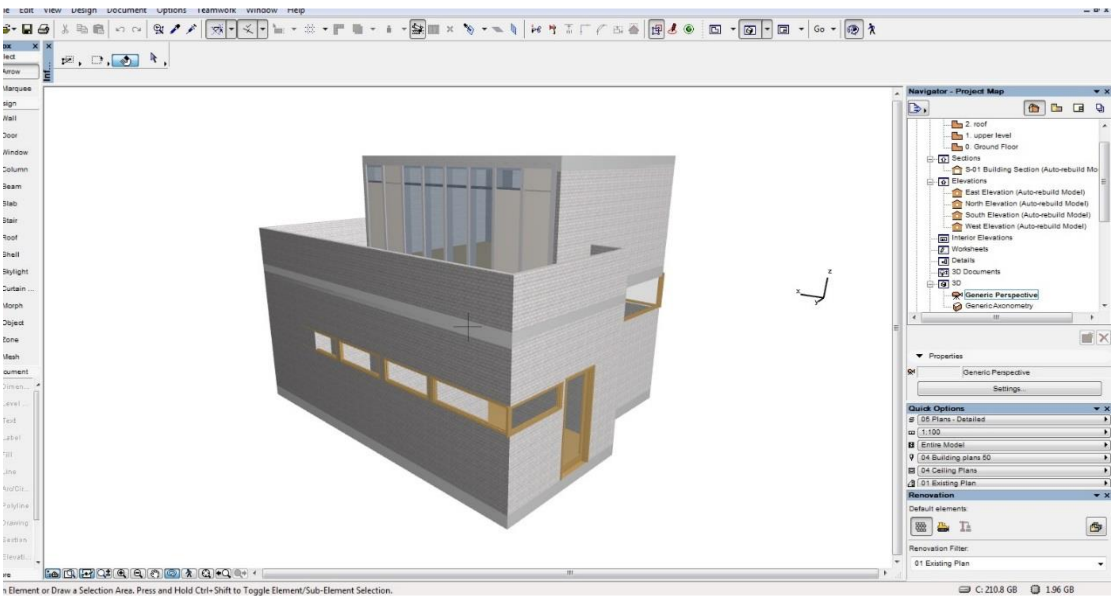




Appendix 4: Design Outcomes

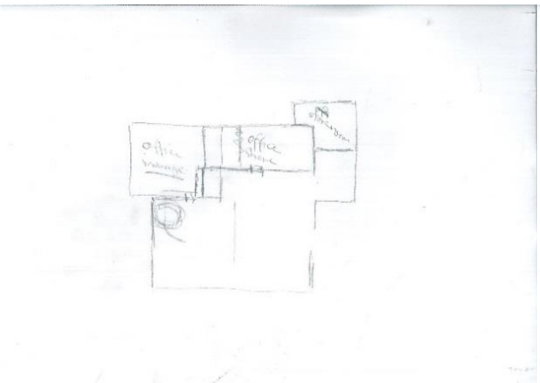
AMM Session: Participant G (Task 1)

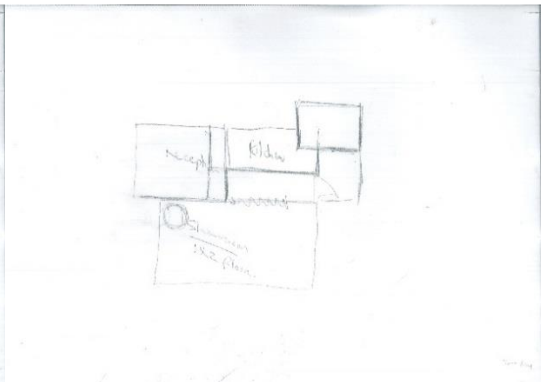


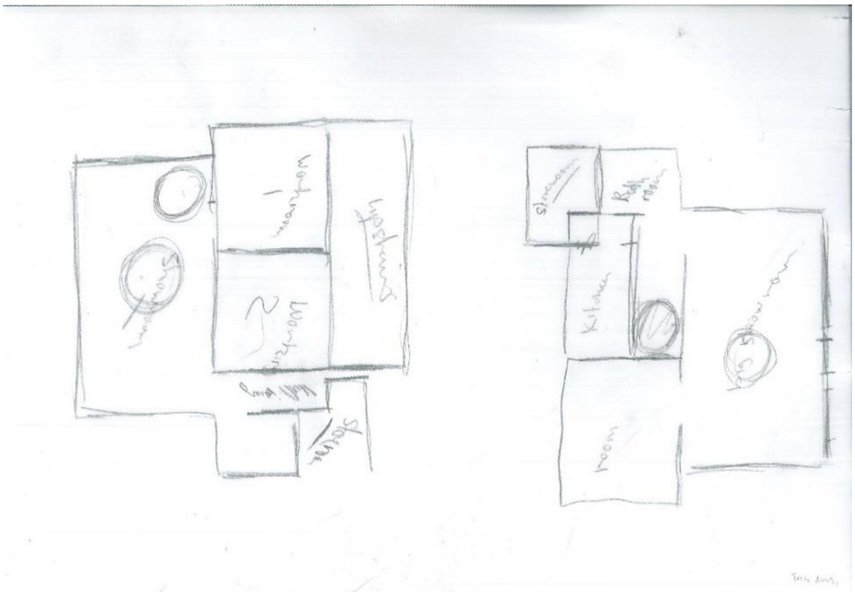


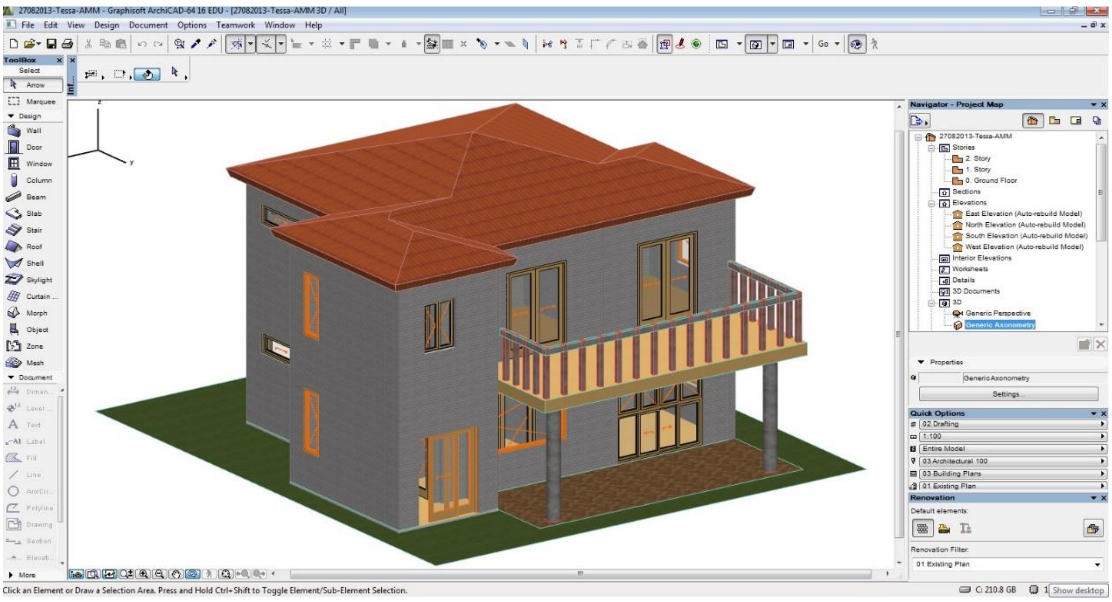
Appendix 4: Design Outcomes

AMM Session: Participant H (Task 1)









Appendix 5: Coding

SMM Session: Participant A

NUMBER	UTTERANCE	FINAL CODE
1	Let’s just start by reading the briefs so, required to re-design the existing house into four, architectural, office, three architects and one manager [inaudible 0:00:28]	Rs
2	some of the architectural designs, interaction with space, it is incredible it just feels.	Bss
3	The office design must use the diversion task [inaudible 00:00:38] modeling such as doors walls et cetera modified and deleted.	Rs
4	There are reasons for this. In relation to design, conceptual designs referral house design coming into the open furniture structure. Okay okey dokey.	Rs
5	Let’s check so today we’re just doing all the sketching first and then doing what … okay. All right just thought I should check …	Bss
6	First thing we want to do is figure out, what needs to be on which floor;	Bes
7	obviously the smoking area on the first floor has to be on the first floor. Include reception, session, meeting room. Kitchen, bathroom, garage, stairs on the ground floor	Bss
8	Let’s walk in first floor	Fs
9	first floor, so first floor needs two design rooms and a smoking area.	Fs
10	Okay. First thing we’re going to do is figure out where the reception needs to be,	Bes
11	obviously it should be at the front door,	Bss
12	so start with a little conceptual sketching layout	Ds
13	We also need a meeting room, kitchen, bathroom, garage.	Fs
14	where these different functions need to be relative to each other, reception needs to be at the front.	Ss
15	Okay, so garage. What else do we need?	Bes
16	It makes sense to have the garage at the front of the building as well	Bss
17	I think I would probably leave the kitchen where it is,	Bes
18	it’s already good old plumbing itself so I can stay there.	Bss
19	Bathroom would need to be fairly central to the design so, let’s just see if [inaudible 00:04:21].	Bes
20	I see the meeting room; the meeting room should be fairly quiet.	Bes

21	Bathroom over here I think, kitchen there, meeting room here.	Ss
22	Kitchen bathroom, bathroom, stairs I think where stairs are.	Ss
23	That just leaves the garage which should go in, basically there.	Ss
24	I think that works well.	Bss
25	Good so let's sketch out, the first floor.	Ds
26	We are going to have a set of stairs over here;	Ss
27	stairs coming out from below.	Ss
28	Stairs are going to come up towards the rear of the building;	Ss
29	A couple of design rooms in the middle	Ss
30	and the smoking area,	Ss
31	it is going to be lucky, a veranda.	Bss
32	I have got a rough conceptual plan of where everything needs to be here in the building.	Rs
33	Next I'm going to start to formalize that design a little bit.	Bss
34	You have a front door here, go in front door, entrance there.	Ss
35	Reception and waiting room, can be over here.	Ss
36	Sketching a reception desk should go there	Ds
37	maybe spill over to the other side,	Bes
38	maybe not.	Bss
39	Put in first so, we're in for some seats.	Ss
40	I want a door through here, bathroom is going to sit behind reception area,	Ss
41	, so clients can get to it nice and easily.	Bss
42	I am sure the bathroom doesn't need bathing shower	Bss
43	so, that's just going to have a toilet, a hand vessel somewhere access to that little corridor and the meeting room.	Ss
44	Meeting room needs to be close to the reception,	Ss
45	I'll get you the two doors.	Ss
46	Doorway through reception and doorway coming from the back hallway.	Ss
47	You have the kitchen sitting behind that.	Ss
48	Stairs rising behind, you can use the back door	Ss
49	and the garage goes at the front. I have to check dimensions for that.	Ss
50	Sketching the walls, a big meeting room table.	Ds
51	Just small compact little kitchen and it needs to have kitchen sink and a few shelves basically, just enough to make coffee, okay.	Fs
52	That's the ground floor sketched out.	Ds
53	That was pretty simple for a simple design, just some stairs rising up round the corner	Ss

54	only winding if we need one and a couple of design rooms.	Bes
55	Sketching some walls, okay and that is basically what we need.	Ds
56	Don’t actually have any dimensions for how big the design room has to be,	Bss
57	it is four, it takes three architects, one manager. We need enough space for two work benches in each design room.	Fs
58	Say about 600, five and two meters for each of those.	Ss
59	Okay and the smoking area out of just the roof terrace.	Ss
60	Okay I think I’m pretty happy with that little set of sketches.	Bss
61	Just going to review afterward make sure I think everything is going to work when it’s drawn to scale.	Bes
62	I think that looks okay.	Bss
63	The benches look sort of okay for the reception area;	Bss
64	I think the bathroom’s definitely big enough.	Bss
65	Priority of the house styled with color material but no furniture so we need to think about what it’s going to look like now.	Rs
66	Let us do a brick house with a tile roof,	Ss
67	has a couple windows in it?	Bes
68	That seems fine, keep the material in.	Ss
69	We need a section I think elevation in front of the house.	Bss
70	We need to figure out what it is going to look like from the street.	Bes
71	The ground line should be one side of the house there,	Bes
72	the front of the house here,	Ss
73	first floor, toward the back architectural facility	Ss
74	so it is fancy with the roof.	Bss
75	Nice big open, skylight I think, lots of lighting to the design studios.	Bss
76	If you wanted to you could also get skylight in another meeting room there,	Bes
77	it should be nice.	Bss
78	That will be grand room actually.	Bss
79	Set out front door here, can have a garage door also in the front of the building,	Bes
80	I think that probably wants to be.	Bss
81	About there a timber would be nice,	Bss
82	a rich-colored timber.	Ss

83	The important elevation taken care of now, to make the front door look a bit friendly a couple of windows, make it look accessible not just a fortress.	Bss
84	Grainy with some description to make it look a little more friendly	Bss
85	, so I am probably going to try set the design room back a little bit and front.	Bes
86	Maybe not, maybe nice big print just thought it would be good, too plain.	Bss
87	Starting to articulate the front door maybe it's in the screen that would work.	Bes
88	A couple of windows will work as well, that I will make out later. [Inaudible 00:16:39]	Bss
89	so, got to check the ground floor drawing.	Bss
90	Start doing some modeling.	Dc
91	Okay, so ground floor okay put out the ring don't need to start with this.	Bsc
92	Just going to start with the internal walls, get rid of the roof clean that out,	Dc
93	some of the windows we are not going to need.	Bsc
94	We have reception behind here, separations in the rest of the building.	Sc
95	Back door is getting moved, there you go.	Sc
96	Now some stairs are going there, so we are going to need,	Sc
97	we have the bathroom, hallway.	Sc
98	Kitchen stays where it is	Sc
99	and I am just rocking in where the walls need to go.	Sc
100	Kitchen area needs to be tiny.	Bsc
101	Let's put in some more doors in, okay.	Sc
102	Now I need to decide how big the meeting room should be,	Bsc
103	I don't know at the moment we have got about, three and a half meters by what's that 2.7 meters,	Sc
104	so that's pretty close. Yeah,	Bsc
105	garage is 3.4 meters long	Sc
106	which is way too short,	Bsc
107	alright 3.6.	Sc
108	The garage needs to be about 6 meters long that is out of the side 6,000 there we go,	Sc
109	I'm assuming there is going to be enough room on the site to do that.	Bec
110	Out here can be the garage door, garage door, out here.	Sc
111	We need a garage door. Then we go the door's we need garage door, what type,	Bec

112	vertical sliding, going to change materials on that materials, five foot frame, leaf so that is two.	Sc
113	Yeah, give it all,	Bsc
114	frame can stay as it was, glass material can stay as it was …	Sc
115	okay.	Bsc
116	Yeah that's the garage door into the front of the house.	Sc
117	I don't want windows in it,	Bsc
118	so happy to get rid of those door panels,	Dc
119	so setting door panel. Here we go.	Bsc
120	Choose a better looking panel or style one, that's what we want,	Sc
121	yeah that's exactly what we want.	Bsc
122	Okay so reception desk, a thousand, need about,	Sc
123	we are going to need distance of about, say 800 for someone to sit on a desk.	Sc
124	The desk needs to be about 600 deep.	Sc
125	We can align that one with our window,	Sc
126	so this one I've seen there?	Bec
127	Maybe not;	Bsc
128	along here if we got room for it,	Bec
129	1500 then we type … how far do we have in here? About 1500 as well.	Sc
130	Come back to that. Okay so I'm just going to let me sketch in where the kitchen sits.	Dc
131	Kitchen needs to quite minimal;	Bsc
132	I should get just bench about 700 deep	Sc
133	might even change that window for a door.	Sc
134	Okay so you'll walk straight into the kitchen after the garden if you want to.	Fc
135	Okay one of the meeting room doors is in an awkward position just …	Bsc
136	I'm going to get rid of it totally put the door in through the kitchen.	Dc
137	Make that look a little bit neater.	Bsc
138	Okay, door into the bathroom coming straight off the reception area.	Sc
139	Where is that bathroom? We can get some more space out of there I think so objects let's just see how big that bathroom needs to be.	Bec
140	Okay furnishing, oh mechanical, plumbing fixtures, toilets, rubber toilets, basins we need a basin and we need a toilet. Here we go.	Sc
141	Toilet under the window and basic and close to that make sure we have enough room for our steakhouse which we don't.	Bsc

142	[Inaudible 00:25:28] say 200, okay so that's about 1.3 meters in there, can't be smaller it needs to be a thousand,	Sc
143	gives us 300 to spare.	Sc
144	Okey dokey we want a door in this hallway as well.	Sc
145	The door is facing the wrong way.	Bsc
146	Come back make part of this wall okey dokey now what is this hallway	Sc
147	and here's 1100.	Sc
148	That's about what we want,	Bsc
149	we need about 900 for someone to sit down	Sc
150	and then a desk needs to be up to 600, 700 deep … 700.	Sc
151	It's going to be a reception desk.	Sc
152	I have it drawn right the first time.	Dc
153	Don't you need this wall out, split that only needs to be 700 high.	Sc
154	Okay I'm sure you have some space in here.	Bsc
155	A hundred … okay	Sc
156	let's check out how we're going in terms of sitting.	Bsc
157	Oh great,	Bsc
158	a couple of chairs, coffee chairs.	Sc
159	Those are worth is a little bit squashy. Okay a little bit more space in here would be nice.	Bsc
160	All right that's okay, that's fine. Okay happy with that offer? Okay that's fine, kitchen there okay so let's go to the first four now.	Bsc
161	Copy some walls,	Sc
162	all right here are the doors that we don't want.	Bsc
163	Okay so we need a staircase that tolls everybody.	Sc
164	We need a section, okay so we need to go up 3.1 meters.	Sc
165	Same here, so you got 3.1 meters,	Sc
166	wish need to do some math's in my head so need to get up 3.1	Sc
167	this we can go up eighteen steps,	Sc
168	I think maximum height is about 200 I think?	Sc
169	Let's say 180.	Sc
170	Yeah so we need a calculator, so staircase, we can have a … where is the staircase? Okay no steps there … okay. First one the steak house can be 1.6 meters?	Sc
171	Which means 1.6, 1100 [inaudible 00:31:57] stairs and landing slab,	Sc
172	no. Put in place and that's sorted out. All right, I'll remember this. Transfer fly beads about a hundred wide … transfer around …	Sc

173	where are the options? Permanent session attributes; this is the first storage, ready for presentation?	Bec
174	No. this is the kind of thing I would have checked before I finished sketching.	Dc
175	Okay so I guess these don't fit very well. We need to figure out how to get them into the building.	Bsc
176	The easiest option is just to move all the walls so as just to fit.	Dc
177	I hope that would be a solution enough. Well … okay. Let's think about reconfiguring our reception area. If we had a bathroom on the outside of this building … that won't work.	Bsc
178	Okay this is the point in time when I want to take out a pencil and start sketching again.	Dc
179	The reception desk … a little there some chairs that are not working here	Bsc
180	and we still have the bathroom at the far corner of the house.	Sc
181	Okay that would work.	Bsc
182	A little bathroom tucked away in the corner.	Sc
183	Here's room for a staircase and here's room for the reception desk.	Sc
184	No good use of the space though the rest of the plane so transmitters.	Bsc
185	The receptionist could make a view of part of the front door.	Fc
186	There will be [inaudible 00:37:26] over there.	Bec
187	No I don't like that.	Bsc
188	People in this corner of the house so people there reception desk over here …	Fc
189	bathroom will go where it was at before.	Sc
190	Okay so what if we try a different type of stairs.	Sc
191	New shapes there looks like could be addressing …	Sc
192	oh we'll need that back door.	Sc
193	Get rid of that wall stair case goes around …	Dc
194	okay that looks better.	Bsc
195	Yeah if we move the stairs completely,	Dc
196	that could work well.	Bsc
197	We have you fixed it that wide and when we get between,	Sc
198	worried about it needs to be all … 2100.	Sc
199	See how that works …	Bec
200	still got a lawn.	Sc
201	Change the dimensions on this;	Sc
202	don't like it,	Bsc

203	more efficient. Put this over, stairs around the back	Sc
204	and so you should have stayed on.	Bec
205	Make it black.	Sc
206	Okay that will work;	Bsc
207	bathroom is going to end up probably in the resting house,	Sc
208	that's okay. [Inaudible 00:42:19] back in here, that's better, that will work,	Bsc
209	take this back to where we had this ours.	Sc
210	This is going to go to the bathroom here just in case. It should work.	Sc
211	Erase some more.	Dc
212	It works, okay so that is working much better.	Bsc
213	The top floor is basically sorted out.	Bsc
214	Okay, reception desk I think works out,	Bec
215	size is a little bit big if anything.	Bsc
216	Session desk will get a little area out.	Bsc
217	That against the door now,	Sc
218	okay, that will fit in there quite nicely.	Bsc
219	Plenty of room for people to sit down that works okay,	Bsc
220	so just fixing up the slam so I change the building just fixing up a few details, getting the model right in 3D.	Sc
221	Can't move, the 200 which means we make it which way?	Sc
222	2600. That's enough.	Sc
223	See how it works in 3D.	Dc
224	It's not accurate but it works.	Bsc
225	I was going to get rid of it anyway, so, lose that.	Dc
226	Pitch the hard on that,	Sc
227	So if it fits.	Bec
228	Just completely fielded by that wood,	Sc
229	I think is right in the middle of the house.	Sc
230	Okay, changing things again still not happy.	Bsc
231	Okay, take that 2400, 2600.	Sc
232	Okay so, still trying to get half those stairs in the building.	Sc
233	Kind of have to watch how used down they are.	Bsc
234	Options, where are we going sort out operations tying in and extraction or an extrusion,	Sc
235	yes … that works reception desk is going to stick in behind that.	Bsc
236	Bathroom is going to stick in underneath, this storage part.	Sc

237	Kitchen and bathroom might need to be swapped over.	Bec
238	Everything under the stairs is storage …	Sc
239	1600 the door,	Sc
240	here there is going to be a reception desk.	Sc
241	Yea, that will work.	Bsc
242	Talk about a hundred.	Sc
243	There's a reception desk storage area here.	Sc
244	We can lose the meeting and the kitchen area, not working how it is.	Bsc
245	The meeting room is going to be at the back of the house now.	Sc
246	Small bathroom in here just give it to that completely.	Sc
247	Much better	Bsc
248	so a bathroom down here, doorway, next to garage.	Sc
249	The bathroom, so it becomes a meeting room at the back of the house tore into the bathroom.	Sc
250	That is much better, much better, okay so the bathroom actually works which is good.	Bsc
251	I wonder what else is going to have to go. Okay that becomes a kitchen, direct access to the meeting room.	Sc
252	We don't even need that wall in there,	Bsc
253	yes we do, no we don't, yea, keep it.	Bsc
254	We have got the kitchen and bathroom sorted out now.	Bsc
255	Reception area seems to be working well,	Bsc
256	reception area leads straight into the meeting room, the reception just have a little bit of storage behind it.	Sc
257	That works for me.	Bsc
258	I guess the ground floor is working now.	Bsc
259	Let's just move this down a little bit.	Dc
260	You'll want people to sit down. Definitely working from here,	Fc
261	okay, so first floor, sitting there still are walls.	Sc
262	[Inaudible 00:58:43] that's one design room in the back and access to the outside.	Sc
263	Okay, just about finished.	Bsc
264	Okay, we need a floor. That should be about sneaking around and that is sorted.	Sc
265	Okay put a roof on it.	Sc
266	Now these things … 100^0	Sc

267	okay so that looks … different type of roof want a cable right on. Okay different type of roofs;	Sc
268	single wired slide roof and a little bit here and get this sublime off its 3D.	Sc
269	Yeah it should be lined	Sc
270	where is my [inaudible 01:02:58] tool?	Nc
271	Oh there it is there.	Nc
272	Okay … just about done.	Sc
273	New cross the planner comes from … there's a line in twenty minutes design, a little bit of operations subtraction and extrusion.	Sc
274	Try to do the upper house for the intrusion and extrusion …	Sc
275	nailed it.	Bsc
276	That's the time inner house hope we don't crush the computer this time.	Bss
277	We twist and that out the garage.	Sc
278	No we don't we screw the refined … well the cable roof.	Bsc
279	Over the garage … okay get that to a height time … operate on the extrusion then we make it.	Sc
280	I think we're done.	Bsc
281	Need a couple of windows … windows … two windows so for ski windows with make them four hundred, next to the doorway.	Sc
282	Okay first floor this is my trace logo.	Sc
283	Difference, that's okay the pathway … windows?	Bsc
284	They are not going to work.	Bsc
285	Windows… okay so tidying up the front of the building with it.	Sc
286	That looks nice …	Bsc
287	I have a frozen tool; remove materials at the door … frozen materials been a long day actually. Photos … zero in … lift. Will I be able to switch? Switch. True … the trim.	Sc
288	Finished? Yeah finished.	Bsc

SMM Session: Participant B

NUMBER	UTTERANCE	FINAL CODE
1	Existing house into a 2-4 [inaudible 00:00:03] for three architects and one manager. Okay. You'll need to focus on the architectural design direction of the space and its overall aesthetic appeal.	Rs
2	If someone you think can arrange a task provided by [inaudible 00:00:35] modify the [inaudible 00:00:38] Okay.	Ns

3	Meeting room, kitchen, boardroom, garage, [inaudible 00:00:51] opens making area office for ... business spaces.	Rs
4	I'll start [inaudible 00:01:10]sketching.	Ds
5	Let's see where to start placing the circulation.	Fs
6	Unlike the house where I put the bedrooms to the south	Ss
7	maybe some of the stairs can go to the south which means the stairs come back	Ss
8	and maybe the bath could stay where it is	Ss
9	We need a reception area	Ss
10	What if you come over here, reception	Ss
11	There can be a small kind of desk against the stairs, I imagine	Ss
12	Put the stairs	Ss
13	maybe put the bathroom to the back	Bes
14	where it doesn't really need nice northern light	Bss
15	and in this might be a split stair [inaudible 00:05:06] around could work	Bss
16	You come in front, and might have a little couch or something, waiting area	Fs
17	and you want a led through to the work, meeting room	Fs
18	What if I build a wall here this enclosed and became a meeting room	Ss
19	and ... Maybe not	Bss
20	Okay. Garage, no garage? No room for garage.	Bss
21	Kitchen, bath opens out in [inaudible 00:06:34] going to come up the stairs here Then that means I got all that space	Fs
22	It'd be good to have some sort of connection with the lower floor	Bss
23	The connection could either be here at the reception	Ss
24	which would feel quite nice	Bss
25	which then means upstairs	Ss
26	You'd have to have a powder room of some sort.	Ss
27	You could probably stack	Fs
28	that here in the south on top of the other bathroom	Ss
29	Bathrooms are done	Bss
30	reception's done	Bss
31	meeting at bottom right	Ss
32	How could I do the kitchen there? Or meeting room, hmm. Kitchen, bathroom, garage	Ss
33	this garage is going to get big.	Bss
34	Why do you want that? The car just takes up too much space	Bss

35	unless you shift all the program upstairs	Bes
36	That's just ... Okay, well let's just try that [inaudible 00:08:47]. Kitchen is down. Kitchen comes back down stairs	Ss
37	You have the bath.	Ss
38	That is going to be difficult	Bss
39	We do need an open smoking area or something, so maybe somehow	Fs
40	How about here?	Bes
41	It pops in.	Ss
42	You could have the managers a bit more private room with	Fs
43	A small deck leading into a semi-enclosed [inaudible 00:10:04] sliding doors...	Ss
44	What if the bath stayed where it is?	Bes
45	You have a little kitchen on the west side where he is at the moment, pretty much.	Ss
46	Meeting room and you go upstairs for the rest of the program	Fs
47	which then means you for a car [inaudible 00:11:25] here	Fs
48	Maybe this kitchen actually becomes smaller	Bes
49	It's huge	Bss
50	Okay, try and fit this car in under the second plan	Bes
51	I've tried to locate it at the southwest corner of the garage door	Ss
52	keeping the stairs in the mural of the south room	Ss
53	This bathroom could possibly stay taking out the cupboard	Bes
54	which is actually not too big	Bss
55	I'll tentatively put it at the back and front of the car	Ss
56	Yeah, that makes more sense	Bss
57	This becomes a bath	Fs
58	This becomes the new kitchen,	Fs
59	north facing deck	Bss
60	and then your meeting room could be something a bit more organic in the center	Ss
61	which then leaves for upstairs I've got to fit in manager's room	Fs
62	You can easily fit a center table with individual tables going on	Ss
63	then they can all walk out [inaudible 00:15:07]	Bss
64	You've got to extend a room.	Ss
65	The managers are first, you've got the three different architects. At the top of the stairs you come up and hit the back [inaudible 00:15:28]	Fs
66	that's fine you can turn the corner	Bss

67	Now you scrap that, take the external room out of there	Ss
68	Make this managing room, angled deck,	Ss
69	make this a much skinnier [inaudible 00:16:11].	Bss
70	[inaudible 00:16:19] come up the stairs, goes through there forget about the bath	Fs
71	The managers, if they want to go to the toilet they'll have to go back downstairs. extend a room, tech media room downstairs kind of sucks,	Fs
72	but... That looks all right. One manager... Let's give that a go.	Bss
73	Carport, lunchroom, media, bath, kitchen, stairs going up.	Ss
74	Let's just put in a desk here.	Ss
75	This can be the meeting room in the open	Fs
76	Make this, this could really just be reception here on the side	Ss
77	It just needs a [inaudible 00:19:11] desk	Bes
78	Then we go upstairs. When we go upstairs, we've got the three architects, get some desks	Fs
79	now facing the shared re-desk	Bss
80	They come to the back and they go to the managing office here They step around and they've got that external room	Fs
81	making open space [inaudible 00:19:51]	Ss
82	Got to give that a crack up	Sc
83	That's not going to work out like that.	Bsc
84	Three meters,	Sc
85	yep, that sounds right.	Bsc
86	Point that in. That's got something... What's this, some decent ones?	Nc
87	Foot lift, about a hundred.	Sc
88	Would just 1600 plus another hundred is 1700.	Sc
89	Hide three meters	Dc
90	and make full adjust.	Dc
91	Landing looks a bit big.	Bsc
92	Excuse me. How do I adjust that? What else?	Dc
93	I start knocking down some of these walls.	Dc
94	I'm now just trying to get the basic arrangements of each of the rooms in terms of the set out.	Bec
95	You have these windows.	Sc
96	You had a pretty top stairs now. Touché.	Sc
97	Let's try and fill up the bathroom now with what we need.	Bec
98	This could work.	Bsc

99	This bathroom is going to get some ridiculous [inaudible 00:27:08] facing work.	Bsc
100	Shower, yes and door, yes, basin, whatever. Just make a bit of a detail out of it.	Sc
101	What else are we going to need to hang, just a shower? I guess a shower.	Sc
102	That could be a bit tight in there.	Bsc
103	A possibility is we just move that over to here make it a pretty big shower [inaudible 00:29:14] cross. [inaudible 00:29:18] cross. Continue.	Sc
104	That's the bathroom.	Sc
105	Maybe not that window there, but we'll get something else sorted [inaudible 00:29:45].	Bsc
106	Get rid of this wardrobe,	Dc
107	telly room's gone.	Dc
108	That goes there.	Sc
109	This shows bathroom.	Sc
110	This is the reception room.	Sc
111	Just change the text here.	Dc
112	We need to do the kitchen at the side.	Sc
113	That goes that, and this becomes the meeting space.	Sc
114	It's going to need some connection to the outside.	Sc
115	Then we'll step it down 400 steps,	Sc
116	which will come off the balcony there, as well.	Sc
117	I'm going to put a slab here at the entrance.	Sc
118	What if I made this reception desk entrance in there and the desk just opposite?	Sc
119	That could work.	Bsc
120	Office chair. Okay, good. [inaudible 00:32:49] Okay, that's that.	Bsc
121	That is wide.	Bsc
122	This kitchen, hit on a bench, sit on a bench.	Sc
123	I'm going to change these doors [inaudible 00:33:54] to the room. Whoop. Just a couple of panels, one, one...	Sc
124	That's what I want,	Bsc
125	two. Six. Fit this door in.	Sc
126	Come on. Beautiful.	Bsc
127	Let's go up a little, take my floor slab with me.	Sc
128	I'll just leave trace on and get some wall action happening upstairs. Could just do this.	Sc

129	Now we said we would... Come up the stairs.	Fc
130	This is going to be the meeting room.	Sc
131	Door, yes. No, yeah, capital.	Bsc
132	Get some tables. I’m just putting in some tables now to get a rough scale of the space.	Sc
133	Doesn't really mend, does it?	Bsc
134	A hundred and fifty.	Sc
135	Let slab this up and slab this up.	Sc
136	You can now flip that door so it so it opens, extends there. [inaudible 00:37:34]	Sc
137	This manager's office this wall there; it's probably going to have to come up to the next level,	Sc
138	unless that's just glass.	Sc
139	Yeah, that's going to look good there.	Bsc
140	I just do like 15 now. Yep, yep.	Sc
141	The garage door upstairs;	Sc
142	how to orientate the manager's office;	Dc
143	you actually want to be able to open this up	Fc
144	and change this door to some sort of sliders. Two pocket sliders.	Sc
145	If we have that that means two of them.	Sc
146	Let's get this, something like this.	Sc
147	Scrap that.	Sc
148	One door, but big.	Bsc
149	He's going to need space at the back of his desk,	Fc
150	so at least 700 and this can be that in this door comes open.	Sc
151	Maybe what would be best is because you're going to have a little meeting room in there as well,	Bsc
152	just chuck these up against the wall.	Sc
153	This is where he works, but, or she…	Nc
154	I'm going to put a glass door in.	Sc
155	Obviously, it has no frame.	Sc
156	Top of the landing of the steps here,	Sc
157	were going to need this door here.	Sc
158	That, doesn't really work,	Bsc
159	does it now? Not the nicest [00:42:31].	Bsc
160	Our resident architects, they're going to fit just in here	Fc
161	and they will need more desks,	Sc

162	actually will love.	Bsc
163	This slab, I'm cutting back	Dc
164	so it fits around the stairs,	Sc
165	in a sum I split a double high-volume at the entrance.	Sc
166	At the stairs is fine. Yeah.	Bsc
167	What else do I need, bathroom? Where else does anything to go up there? Maybe just as exterior room.	Bec
168	Now I'm just putting some glass doors, glass sliding doors across the front of the property, across the north side,	Sc
169	sorry, and this should offer them... I could actually slide beyond that.	Sc
170	Let's make these like two meters.	Sc
171	Okay, that's going to be two meters yeah,	Sc
172	25, yeah.	Sc
173	Two meters wide, the doors.	Sc
174	At least that one slides beyond the building,	Sc
175	whereas this one has to stop. I have to... We'll just put an empty window there,	Sc
176	for the city. I'm going to cut back the slab.	Sc
177	These steps are going to come down.	Sc
178	I think. Yep. That's the front of the steps done	Bsc
179	and I'm going to very similarly replicate that down here,	Dc
180	get rid of these puny boys.	Dc
181	Right off of that, need a slight deck on the top here.	Sc
182	Three architects, this is going to be that semi-enclosed room.	Fc
183	Why don't we drop the walls?	Bec
184	Make them 300 high,	Sc
185	get rid of that boy.	Dc
186	Maybe not, what's going on there? Why is that messed up?	Bec
187	It's going to make this with no [water 00:49:06], so it fits.	Sc
188	While it's doing it, should be able to suggest a roof here.	Sc
189	I don't know. This is going to be that external room.	Sc
190	That's not what I want.	Bsc
191	Leave this like this jutting out pitch.	Sc
192	I'm not sure what to do about this little area	Bec
193	doesn't quite line up nicely like I would have hoped,	Bsc
194	but the alternative is we let go and make it into a printer/stuff room.	Bsc
195	You'd have to go outside there.	Fc

196	It's no huge space,	Bsc
197	but, or here, why don't we do that?	Bsc
198	Now I think I've got that almost figured.	Bsc
199	These walls come this becomes the outside room back up.	Sc
200	Doing a [inaudible 00:53:48].	Nc
201	This is not the worst.	Bsc
202	It's a narrow balcony,	Sc
203	but you just open that up. Kind of same as that grab that change the heights in the [inaudible 00:54:23] railing.	Sc
204	Have it there, a nice handrail along here, and one across here.	Sc
205	That's going to make the grass slope as well. Grass, grass, grass,	Sc
206	okay. Let's finish off the reception area.	Sc
207	That there is looking a little bleak.	Bsc
208	Just need sink, okay. I still need a fridge.	Sc
209	Now I'm just trying to work in 3-D a little bit and finish off.	Dc
210	[inaudible 00:58:10] Let's make it look half-respectable.	Sc
211	Okay. This also works here.	Bsc
212	We need a door going into the bathroom.	Fc
213	What is that? [inaudible 00:58:52] Maybe get rid of that,	Dc
214	he's just coming out of the garage door like a sad sob.	Fc
215	This meeting space, let's make a table. Now some chairs around it.	Sc
216	[inaudible 01:00:18] I would like a bunch of these scattered around and it's here.	Bsc
217	Let's make the width.	Sc
218	It's going to be a 2800 total.	Sc
219	It's going to be a bit of a biggie,	Bsc
220	but I'll try to orientate it here.	Dc
221	It might be better going another way,	Bsc
222	then it can't be quite so long.	Bsc
223	Make it 2200	Sc
224	and we can fit sunny of chairs around that unit.	Bsc
225	Come on. Um-hmm, okay.	Bsc
226	The receptions at a slightly weak part at this point, which I think;	Bec
227	bring the entrance back up here	Sc
228	and... It needs to somehow get around there,	Sc
229	not going to have the head clearance by ten steps, unfortunately.	Bsc

230	What might end up happening is you just set a table up against that and just got to keep this shit clean.	Sc
231	Okay.	Bsc
232	Reception in big meeting space,	Sc
233	plenty of room not double height,	Sc
234	but that's all right,	Bsc
235	you can walk out; walk into the kitchen quite successfully. You can walk outside; you can get to the bathroom	Fc
236	so that's a tick.	Sc
237	Meeting room, reception, hallways [inaudible 01:04:23] okay. This looks like shit.	Bsc
238	Let's do in 3-D.	Dc
239	You never do that ever.	Bsc
240	This is in 3-D;	Dc
241	mess around a bit with in fenestration.	Bsc
242	What is going on there?	Nc
243	[inaudible 01:06:19] is.	Nc
244	Actually, I am not too happy with that.	Bsc
245	What is a good way to light that up?	Bsc
246	They need to be lit underneath,	Sc
247	but it looks good like that.	Bsc
248	How big is this desk?	Sc
249	Get under and make this smaller.	Sc
250	Stop creating copies.	Bsc
251	Actually, remove this [slabo 01:07:59].	Dc
252	Guess, I'll have fenestration going straight up the wall, could be done.	Bsc
253	Excuse me. Now, I'm just adjusting the wall	Dc
254	so it goes up and meets the underside of the top wall.	Sc
255	That way my window can just go all the way up,	Sc
256	what might be the easiest thing.	Bec
257	I hate that it picks up the garage,	Bsc
258	might just chop this wall here	Dc
259	and delete	Dc
260	and just bring then do the same on both walls.	Sc
261	Chop it there.	Dc
262	Bring this up;	Sc
263	it's going to show [inaudible 01:09:23] stories.	Dc

264	This then pops all the way up.	Sc
265	This also does. Come on window.	Sc
266	Wake up you silly twit.	Nc
267	All right, I'll just put some things across here to set aside,	Sc
268	to put the other frameworks aside.	Sc
269	Fifty,	Sc
270	so I make them in them a hundred.	Sc
271	Boy.	Nc
272	Now I'm just trying to get Maximilian to work here.	Bsc
273	That's kind of funny,	Nc
274	but that's all right.	Bsc
275	Switch, there you go.	Bsc
276	Anything on the sliding doors.	Sc
277	I need just a normal opening door.	Sc
278	That's going to come over here.	Sc
279	Come on, and a hand railing that comes across looks to...	Sc
280	You kidding me,	Nc
281	just move.	Dc
282	All right.	Bsc
283	At least I got the shrink of it.	Sc
284	All of this has to come forward.	Dc
285	At least I got the shrink of it.	Sc
286	I don't know with that slides. It sometimes disappears.	Bsc
287	Okay, that works.	Bsc
288	Tick, tick, tick. Entrance.	Sc
289	To get these door hoods up, I’ll need something for the bathroom,	Sc
290	can't be a dark room.	Bsc
291	What's going on here? How is that [inaudible 01:15:16]?	Nc
292	All right, some windows for the bathroom just up top,	Sc
293	I think kind of a string.	Bec
294	It could even just be empty, could be open.	Bec
295	This is the fenestration for the bathroom.	Fc
296	That's here, also going up, a high-level windows.	Sc
297	Yep. [inaudible 01:17:19] at it. Kitchen's okay.	Bsc
298	Meeting space, [inaudible 01:17:33], upstairs bedroom.	Sc
299	That's just making here outside.	Sc
300	This is the [inaudible 01:18:01] the first.	Nc

301	Well could, yeah.	Bsc
302	Workstations. This is deck. This is another deck.	Sc
303	These are some more [sheddy's 01:19:26] one story up and a ...	Nc
304	How do I do that? Let's see,	Bec
305	it’s a void.	Nc
306	reception area, meeting, kitchen, bathroom, garage, [inaudible 01:20:13], stairs, [inaudible 01:20:14 to 01:20:19] brief.	Rc
307	All right, then I guess now I just go put a roof on it.	Sc
308	I see something a bit funny.	Bsc
309	Hmm. It's over.	Nc
310	And then the other thing is both. There we go. Make it.	Bsc
311	I like it	Bsc
312	If I cut that, [inaudible 01:22:06]	Bec
313	cut that,	Dc
314	bring it up	Sc
315	and paste.	Dc
316	Goes below	Sc
317	but I want to copy, paste again,	Dc
318	make this about a 600 shift,	Sc
319	so I turn 600 and then from this one,	Sc
320	I'd like to [inaudible 01:22:39]. This guy.	Nc
321	This is going to get out of it now.	Nc
322	It's got a bit more pangs out like a shelf. It looks fine.	Bsc
323	Maybe 500, let's bring it back in.	Sc
324	Excuse me. Let me grab some of this and get… oop...	Nc
325	All right [inaudible 01:24:34].	Nc
326	Now I'm just going to finish up doing the design of the roof, which should satisfy.	Bsc
327	I'm just going to make the smaller.	Sc
328	Hmm. Then another slab that fits, well we'll do this one.	Sc
329	It would be nice to [inaudible 01:25:59] up.	Bsc
330	If I had more time I'd actually want to do a bit more of a [inaudible 01:26:51] roof, I think.	Bec
331	This is going to have to do for right now. I'm now just going to try it, make it center.	Sc
332	I'll make that into a roof.	Sc

333	Hmm. Okay, these would just be where the water drains out of this is probably some solar panels [inaudible 01:28:47] on the top with some gutters on the way.	Sc
334	Do need some fenestration here.	Bec
335	Yeah, that's cool.	Bsc
336	Maybe two windows.	Bec
337	Woops. Not too fond that area, but [inaudible 01:31:25].	Nc

SMM Session: Participant C

NUMBER	UTTERANCE	FINAL CODE
1	Okay, design problem…. The gallery is for two salespeople with one manager, okay, we'll focus on the customers' interaction with the space. ..	Rs
2	I'm not going to do a garage	Bss
3	because they can always park outside.	Fs
4	Big balcony will be to the north somewhere.	Ss
5	Kitchen, bathroom, storage room - kitchen, bathroom. The kitchen, bathroom, storage room, stairs, two working rooms - two working rooms? Two salespeople and a manager with two working rooms	Rs
6	The whole ground floor should be as much gallery as possible,	Bes
7	so let's get rid of that.	Ds
8	So I'm going to enter in the same place, or even in there; it doesn't matter	Bes
9	because basically we're going to clean up as much as possible here.	Ds
10	Might just have something in there.	Bes
11	Basically we need to get as much gallery in here as possible, and the kitchen;	Bes
12	if I had a ruler I would measure back here	Bes
13	and just get a nice galley kitchen in off here;	Bss
14	but even that's probably okay because you're going to use it for preparation for	Bss
15	so if we did bathroom that side	Bes
16	and then we breakthrough basically	Ds
17	have another room, a nice clean room where the bathroom goes off.	Bss
18	Maybe leave that kitchen near that room in there.	Bes
19	Move that cupboard.	Ds
20	I see what's coming into the existing bathroom. Then you can come out	Fs
21	and there might be a sculpture garden or something out there;	Bes

22	leave the utility room there.	Bss
23	Something like that. so you come in to a nice big gallery space;	Bss
24	open that all up;	Fs
25	kitchen I'm not allowed to touch that yet so I would go okay well I'm going to use this	Bss
26	so basically the space you want between two things in the kitchen is 1200	Ss
27	so I'm just going to go same as that again; that, same as that again there.	Bes
28	I'm going to pull all that stuff in and put it there,	Bes
29	which means I need to redo that door.	Bss
30	That's not so bad. Or is it? Or is it?	Bss
31	I'm moving that wall.	Ds
32	Yeah, doesn't matter I guess. For the moment it doesn't matter because that can be changed.	Bss
33	So for conceptual design it doesn't matter because that really - I'm talking about the wall and that door and everything, so let's just leave that.	Bss
34	So all the ground floor is really going to be left except for breaking through, probably there.	Ss
35	So galleries; you want nice	Bss
36	so I'm going to break that there. I'm going to break that one there;	Ds
37	nice archway through to another space.	Bss
38	Whether that's kept, who knows?	Ns
39	Utility, leave it.	Bss
40	Put some nice - maybe leave those windows but put a nice door in the middle	Bss
41	going out so there's the ability to sort of close, open, change, they can always block it off - and out to sculpture garden.	Fs
42	The balcony would definitely be over the top of that.	Ss
43	Take it all the way to the top of that above, so, okay.	Bss
44	Then top floor - so then to find a good place for the stairs.	Ss
45	They're going to come in here	Fs
46	and the stairs should go in the middle of the space; up through	Ss
47	I'll just put it up through here. Just put it straight up in there.	Ds
48	I don't know; put it straight up, so four metres,	Ss
49	it's going to be, like if that's 2.5,	Ss
50	so you want that wall area as much as possible.	Bss
51	I'm just going to do the same again basically; up through the middle; basically up to there	Ss

52	and they get to about here upstairs. They get to about there somewhere upstairs above all that.	Fs
53	So then there's a stairway through this space.	Ss
54	See what happens.	Ns
55	You've basically got to put the square up the top again like that.	Ss
56	You arrive up here and you've got the big showroom downstairs	Fs
57	kitchen, bathroom, storage room also downstairs; they're going to be somewhere in there	Bes
58	Two working rooms with a big balcony on the first floor.	Bss
59	Two working rooms with a big balcony, well the big balcony could actually just - should be about three metres;	Ss
60	that should be just nice and big;	Bss
61	let's just centre it there.	Ss
62	Just take it out here. Probably it will end there somewhere; and two working rooms.	Ds
63	I think I'd keep everything very loose if it's an art gallery.	Bss
64	So I would make that there come to the top of the balcony, come out, there's balcony [0:10:00.1] and you also come out to a work room there which is sort of overlooking the stair coming up and maybe a work room here which is also overlooking the stair,	Fs
65	so how about we do that?	Bes
66	Two big spaces that talk to each other	Bss
67	and downstairs and then you come around, so it's a very open top floor; basically mezzanine up there; stairs in the middle; land there; nothing across; very open. So work rooms to the side like that.	Fs
68	Stairs down here somewhere;	Bes
69	even if it's a spiral stair or something.	Bes
70	May as well do a spiral stair; see what happens.	Ss
71	Balcony; big balcony. Existing roof will come round like that and just be in there.	Bes
72	This here will be that. that there is going to be existing roof down there;	Bes
73	similar to before; big void in the middle	Ss
74	possibility of doing even artwork up through there;	Bes
75	interesting; double height.	Bss
76	Walk in here; so spiral staircase there; landing up there somewhere.	Fs
77	Storage can be all here on the south anyway	Ss
78	it's not really a storage room, but its storage enough.	Bss

79	There can be; what did I say; gallery here.	Bss
80	Whatever happens to the kitchen, sorry gallery,	Bss
81	well we break that, [do that in there] just in the middle.	Ss
82	Put the wall; break the wall there so there's an archway there.	Ss
83	Then basically all that becomes like a sort of a, the ability to do storage.	Fs
84	God knows what that is.	Ns
85	They stay as bathroom, stay as utility; this is big space and this is definitely staying kitchen.	Bss
86	Okay, so as a starting point I can leave that now; just note for myself balcony, roof, roof, work room one , work room two, spiral stairs up, landing;	Ns
87	I know that will work.	Bss
88	Mezzanine up here, possibly. So this is showroom. Off to the gallery there. Off to the bathroom here, so existing door. Kitchen there. Ability to go out; you can always get guests out. Sculptures, all sorts of things.	Fs
89	from what I have drawn which is very rough, to make it work on the model, which should be easy enough.	Ns
90	I have got let's say half an hour left. I should be able to do it.	Ns
91	So this time it's not really a square on top, but it's just coming back, so it's actually - I just want to create that; the right shape again.	Ns
92	Okay, so this roof I copy, I paste, and then I put a copy into that trash. [0:15:01.3]	Dc
93	That was hidden there anyway. I could have used that I guess, but I always create my own.	Nc
94	Now this wall here is going to go back and	Sc
95	ooh, no I won't do that	Bsc
96	Right click converts to split to single pane;	Sc
97	split anyway,	Dc
98	and delete that one.	Dc
99	Basically deleting that one.	Dc
100	Delete that one	Dc
101	Probably splitting that one	Dc
102	Doing a slightly different to the view before. That's right.	Bsc
103	Yeah, keep the roof back to there. Put this roof back to - [unclear] big balcony,	Dc
104	so in the middle of these things.	Sc

105	Oh we'll see what happens. That one there coming down.	Sc
106	Slab. Slab, slab, slab, okay, creating a slab there;	Sc
107	alt pick up that; the properties of that wall; flip and send it over to here.	Dc
108	So that's going to be - if I pushed it to there I can see now I've made a mistake already,	Bsc
109	so that's actually going to be a bit up here somewhere,	Bec
110	so about the width of a circulation which is 1200. So let's just call it 1200.	Sc
111	Now these are going to intersect; all these are going to intersect, so I choose them all; edit; reshape; intersect.	Dc
112	So that's now my thing. Just see how big this balcony is.	Bsc
113	It's 2.8,	Sc
114	yeah, see it's going to be at least that, so it's going to come out to at least that roof, which is fine, which is what I wanted.	Bsc
115	It's even going to be more than that.	Bsc
116	I think it's going to be at least three metres wide.	Sc
117	Three metres is about the minimum you'd want to put a table on	Bsc
118	so hate to restrict it to anything less than that	Bsc
119	and it's going to be coming somewhere - out there somewhere.	Bec
120	So big balcony. Get rid of that,	D
121	I don't know. So that space, this is hard, okay, so [unclear] we decided was okay	Bsc
122	I might just bring that slab in to above that, because that's where it - up to the bottom	Sc
123	and I'm going to have to create that coming around to there and that one there coming around to there.	Dc
124	Now, ah, okay so working out where the mezzanine will be.	Bsc
125	I'll just rough it out for the moment, and this should be I guess a 1200	Sc
126	because I was using the basically editing tool to measure, so 1400 you're going to need at least	Sc
127	well I may as well make it line up with that - [is that what you said] here	Dc
128	, so I'm looking now for what I did downstairs.	Dc
129	I'm basing it off that. Of course I want it	Bsc
130	yeah on the inside of that wall down below, which now makes it 2.8 wide, yeah that's minimum.	Sc
131	That one there is 1150	Sc
132	so add 650 to it to make it 1800	Sc

133	and then add another metre to make it the minimum work room size. [Lose some on both].	Sc
134	So the work rooms are going to have to be less than that.	Bec
135	I have worked in less than that.	Bsc
136	Have to lose say 600 off both.	Sc
137	Can see there it's interfering with the windows downstairs - that's where the windows are downstairs.	Bsc
138	So now we've got a 2200.	Sc
139	Okay, well that door is not there and that door is not there. Let's just get rid of those.	Dc
140	I'm actually trying to design now in CAD,	Bec
141	which is actually very hard.	Bsc
142	If I look at the south elevation I'll see it's got those four windows, which is not great.	Bsc
143	We don't need them at the top. They are at the bottom. They are fine at the bottom.	Bsc
144	What we actually want is to redo all the windows	Bec
145	and give us nice sun and light.	Bsc
146	Yeah, we'd want like a nice big double height southern light.	Bsc
147	Okay, let's do that. So let's change the window.	Sc
148	It's just going to be a special ribbon window of sorts.	Sc
149	Just a simple - oh that's just the one they've chosen.	Sc
150	I don't want the openings. Fixed, fixed, fixed. Ah ribbon windows fixed.	Bsc
151	It's pretty much really I want it in place where the old one - mm okay	Bsc
152	I'm going to have to extend that whole roof up	Sc
153	Oh no,	Bsc
154	yeah. Get rid of that.	Dc
155	I'm pretty much putting the window where the other one wasn't. Okay, floor to ceiling window; why not, everyone loves them.	Bsc
156	Only want one.	Sc
157	Just trying to get rid of those things; options; custom; corner; window sizes; window frames.	Dc
158	Don't want those three panes, but anyway.	Bsc
159	Want to move those off to the side and so if I move them;	Dc
160	so yeah 1200; another one there.	Sc
161	I'm sort of getting a symmetrical thing happening here.	Sc

162	Go ground floor. Okay. I think that window was put in wrong. Yep.	Bsc
163	Okay, so south elevation now should look like something like that.	Bec
164	Putting this one up which I learnt before is 3100 and I'm going to put that one up there.	Sc
165	So some sort of floor to ceiling window thing happening right through the guts of it. It's an art gallery it's got to look good. [0:25:01.3].	Bsc
166	These guys need their work light,	Bec
167	actually, but I don't need that to go all the way up to there, so I'm going to do that. I'm going to turn these into those, but I don't want them to be	Bsc
168	I want them both to just be say 900 off the ground	Sc
169	or actually 1100	Sc
170	Oh, hang on. So I take the 1200 off.	Sc
171	Control drag onto the top of that top line.	Dc
172	. [Unclear] 2400.	Sc
173	So now we've got this sort of art gallery type façade	Sc
174	which I'm assuming is the entry. Assuming the entry is out here.	Bec
175	So now the ground; that storey now works because you've got these two spaces here that are accessible, workable, interesting void through the middle.	Bsc
176	So we need some stairs.	Bec
177	I'm just going to put a spiral stair in	Sc
178	because really that's a good; it's just a good marker and gives us space and if you want to do something different with the stairs you can always do something different; and they take up not much room as well.	Bsc
179	So I'm really just using it as a marker; a way of - I don't think that's going to work.	Bsc
180	. [Unclear] these things look like in plan - ah, that's right. Okay.	Bsc
181	So, okay, no, flight width, the flight width is radius overall.	Sc
182	It should be about, yeah, 112.	Sc
183	Oh that's - okay, that's good	Bsc
184	Control Z	Dc
185	, so 1400	Sc
186	The flight width is 1200.	Sc
187	Yeah. Perfect. So it's the landing I presume. I’m going to show it one storey up as well. Oh that is, okay, let's do up and down. Okay. I'm going to show it landing, ah, there we go.	Bsc
188	X, so cut, paste.	Dc

189	Yes. Now it's showing up here. Better just check that that's showing, ah; ground floor; check that that's showing one storey up. Okay. So check that. That's obviously landing there which has to be	Bsc
190	so control E - has to be there lined up with that.	Dc
191	That's a big space.	Bsc
192	Okay, so things aren't quite fitting in the way I wanted them to; and that is not looking that good, so that's clashing with that; the bottom there, the spiral stair is not really helping me, unless I bring it back another,	Bsc
193	yeah 1200	Sc
194	I mean 600.	Sc
195	I brought it back 600 before, so why not.	Bsc
196	Ground floor why would you [0:30:01.1].	Nc
197	Take it back to there. There's something about this massive space; that wasn't meant to happen. Maybe we put the stairs back on each other, so how much space do I need for those?	Bsc
198	Two metres,	Sc
199	yeah, okay.	Bsc
200	What about if I do that; change the type of stairs	Bec
201	because it's just not working.	Bsc
202	Basic stairs. Basic stairs, complete stairs. Yeah, U shape	Sc
203	Okay. Bang. Okay, total width; total width - bang, okay, so now is that going to be [unclear] one storey up, okay	Bsc
204	Probably have to be there somewhere.	Bec
205	Oh god, there's no space. Bloody stairs, but they're going to wind. Stair settings.	Bs
206	They're going to wind so there's going to be a bit more space there somewhere. I'm going to have to assume that.	Bec
207	Don't enjoy these stairs at all.	Bsc
208	Ah, okay, time, time, time.	Nc
209	I'm running out of room here. I really want to turn that back out to there just don't need all this space.	Bsc
210	Okay let's just assume that all works and somehow you're going to get this.	Bec
211	Don’t enjoy stairs at all. Okay, so there, whatever. Okay, I hate these stairs. Get really annoyed by them, but that's fine.	Bsc
212	The basic layout of that will probably be something like that. Have some sort of interesting stair;	Bsc

213	there's plenty of room to move - 3600 -	Sc
214	plenty of room to do something interesting	Bsc
215	and get your stair up to there.	Sc
216	That has to be the way it works. That is not right though. So hate the way that works.	Bs
217	Okay, so that's the whole showroom with the stair right in the middle of it, [0:35:00.6]	Sc
218	but that's cool because you'll pass under it and something. Yeah, it'll only take up that much room, so I'm just using that as a marker, but then it'll go further.	Bsc
219	So there will be this landing there. You'll walk in, you'll walk in and you'll see the art gallery,	Fc
220	uh you don't see that any more. You have to split that.	Bsc
221	o view, reshape, split to there and lose that door. Split that back to -	Sc
222	ah, control, control Z, control Z,	Dc
223	that's how I like, just leaving if I'm assuming it right	Bsc
224	try alt Z,	Bec
225	ah no	Bsc
226	Okay, edit, reshape, split through there.	Sc
227	Oh that's right. That's okay	Bs
228	Get rid of that door	Dc
229	and then I'll take that wall back just so there's a bit left over.	Sc
230	Oh that's right I was going to actually do that.	Bsc
231	So back here I'll assume that I'm going to actually leave some cover, say to there, so that you get into the bathroom okay.	Fc
232	. That's kind of an unknown. That's now your extra thing. We don't know what's happening in there.	Nc
233	We might extend that out a bit. Oh still don't really - that stair and whatever is happening above	Bec
234	That's into the kitchen. That's your showroom. So showroom. Upstairs balcony, pretty much done in terms of layout.	Bsc
235	The ground floor that could happen anywhere in there,	Bec
236	so I'm going to remove; I'm going to put a few different walls in just as a maker for where these things might end up.	Sc
237	That one there was going to be a good, wow,	Bsc
238	let's just put it at 450 there, yeah.	Sc
239	That one there, I'll just put another 450.	Sc

240	So there's a good 900 there, so it's just a bit of a marker, but they want a storage; we can do that up there, plus you've got that gallery space plus you've got that.	Bsc
241	Going to have to get rid of that window there.	Dc
242	Going to have to get a nice door in there.	Sc
243	Get rid of that window there.	Dc
244	May as well turn that into something,	Bec
245	oh no hang on, I'll flip that and put it just centrally I guess in the space for the moment.	Sc
246	So there's a way of getting out and back. Kitchen at the moment, there's a way of getting out to the back.	Fc
247	Oh hang on, no, we don't want to split that. Settings, sub-door.	Bsc
248	So now enter, showroom, stair; showroom, kitchen; kitchen is mostly left the way it is. If I just show that; ground floor, so down, okay. Think I'll be able to see it sitting over the top there. That's okay.	Bsc
249	Should put it; how far is that one from there?	Bec
250	Let's just get some symmetry in here; why not	Bsc
251	1050, 801, take it back 1050, so that'll be to there.	Sc
252	It means that when you get upstairs you will basically hit a nice symmetrical place even if the roofs are doing something slightly different.	Bsc
253	Okay. Ah, what are you doing over there? Fix up these roofs.	Bsc
254	So there's a roof in there. There's a roof in here. A roof in there and there will be details of how that actually gets manifested	Sc
255	but basically those are the left over downstairs roof. This is the upstairs roof and work area.	Fc
256	Need windows in there	Bec
257	so I'm actually use the downstairs windows.	Sc
258	. Oops, oh that's just the same as these,	Bsc
259	so alt, put them across, inside, inside - oh hang on, so they're going to	Dc
260	let's say we do something like, yeah, we'll opposite.	Bsc
261	So really just making design decisions based on symmetry not much else at the moment, which is not really how I'd end up designing, but it's just working for the concept.	Bsc
262	So for the moment we need to get some doors in here;	Bec
263	doors; sliding doors; hang on. Sliding doors; yep, the door.	Sc
264	Okay, drag it across	Dc
265	so maybe 133	Bec

266	150, just for the sake of it.	Sc
267	So there are some sliding doors at the top of the stairs; assuming people get there, and can walk out. These people here who work there and there can also walk out, so everything is sort of display; it's loose, it's open.	Fc
268	Utilities are sort of north which doesn't really work, but we're trying to use that space as much as possible.	Bsc
269	The staff can always enjoy outside; so can the patrons. There's all this outside that can hidden, so turning this into an art gallery everything's very open.	Fc
270	There's north and south light. Don't need the east and west.	Bsc
271	Ground floor have east and west entries; south skylight.	Bsc
272	Everything else will be controlled probably at that level, and certainly to the north well you just make do with what you've got or do what you want.	Bsc
273	That will be quite dark.	Bsc
274	It's shaded anyway so you may as well just have a sneaky door there similar to that.	Fc
275	We'll work that out and there would be sort of detailed design decisions there.	Bsc
276	I guess I should move that door	Bec
277	it doesn't really make sense there,	Bsc
278	but I think that door would really in the end be opposite whatever	Bec
279	no, just leave it.	Bsc
280	Let's look at the north elevation and see if it looks okay	Bec
281	It looks okay.	Bsc
282	Need to make that balustrade look okay.	Bec
283	This stuff here - so people mostly would be seeing that; so there's this new symmetrical thing; east, west just box;	Fc
284	so I'm basically extruding a box	Sc
285	so it's a very simple idea.	Bsc
286	Still haven't done the roof. I think I might just do what I did in the last one	Bec
287	and just put that back a square roof because even if that - yeah.	Sc
288	Ground floor; so control L, look at the trash, get the roof, copy	Dc
289	go up to the top	Sc
290	paste. Just paste it back in; just basically put it back. Oops. [0:45:00.2	Dc

291	Ah, but this isn't the perfect square now because it's coming back over, so say west elevation; that's not right.	Bsc
292	So, go to the storey, bring that back to -	Dc
293	oh well hang on, oh no,	Bsc
294	let me get rid of the trash.	Dc
295	. Argh. Control V,	Dc
296	what's in there? Oh, didn't change it.	Bsc
297	. I thought I changed it.	Bec
298	Yeah, so that doesn't look right	Bsc
299	but there is a balcony there which can sort of benefit from it	Fc
300	So would I use that same roof for the balcony?	Bec
301	Look at the perspective and see.	Dc
302	That's kind of okay; looks a bit funny but it's basically okay.	Bsc
303	Yeah that's like pfft, I mean there are a lot of things that can happen with that elevation.	Bsc
304	This one here is less to be looked at and more to be used, and some beautiful north needs to come in there.	Bsc
305	If we change; now let's have a look and see what that could be like.	Dc
306	Let's see if I can edit it here.	Dc
307	Yeah. So it could come all the way out to there and sit over the top of that and sit over the top of that and sit over the top of that.	Sc
308	Yeah, I wouldn't advocate that because certainly you've got this bizarre covering to that space.	Bsc
309	What I'd want is the same sunny covering over that whole part,	Bsc
310	so what I'd be doing is actually putting a different roof on,	Sc
311	which made sense of all that.	Bsc
312	How about making it a box?	Bec
313	Okay. Just put a new roof on.	Sc
314	Get rid of this roof. Get rid that roof.	Dc
315	Put a new roof on	Sc
316	that is just; okay, let's just start from scratch.	Bsc
317	I'm just going to see what's, ah, just a simple old roof.	Bsc
318	That's its pitching point. We can always change it later, and it's going to look something like, oops	Sc
319	it's [unclear] about 900 really	Sc
320	I just wanted to touch some - so, oops, okay, so it only needs to be about a five degree pitch and it actually needs to be running the other way	Bsc

321	so I'm just going to make that minus five degrees and I'm going to bring that down to say the ceiling level, but I'm going to move that up to, yep, 400.	Sc
322	. South elevation 3100. East elevation, west elevation 900.	Sc
323	[0:49:59.7] Okay, so a parapet roof all round,	Sc
324	that way we get this nice art gallery box.	Bsc
325	Going to have to now quickly fix this - 3100. 3100 in this case,	Sc
326	unlike the architects, there's no need for anything else because that'll be able to add something maybe to the entries.	Bsc
327	Yeah, it's going to be work on the entries;	Bsc
328	maybe that will even turn into the entry or something.	Bec
329	So again as a concept it sort of works.	Bsc
330	It's got presence; the rest sort of just needs to work and make a nice space	Bsc
331	That's your big balcony.	Bsc
332	There's a wall that doesn't need to be 600;	Sc
333	only needs to be 2400 probably.	Sc
334	Uh huh. So that reduces down to there. Okay, make that 2600. Yep.	Sc
335	So, roofs out there, big balcony, spaces out the back to use; existing roofs; parapet wall; street presence; pretty much done what I said I was going to do there.	Bsc
336	Haven't resolved some internal stuff, but I don't think I can do that until either I really struggled over those stairs - which I don't want to do and I wouldn't, not for this type of thing because I know it can be done	Bsc
337	or I started really working out how to use those spaces and if they were big enough. So as a beginning concept I think that's pretty good.	Bec
338	I might just now run a sort of a solid wall around there with a balustrade on top or something,	Sc
339	because that's the sort of thing that might end up making sense.	Bsc
340	Probably just a solid wall; a low solid wall and [assuming] a glass balustrade or something.	Sc
341	So I'm moving; use this wall;	Dc
342	alt and then those. Alt G.	Dc
343	Okay, it's only going to be one metre high; so there's that.	Sc
344	So it's a sort of terrace that just sits underneath those windows which is kind of nice.	Bsc

345	So again we've got this full symmetry of internal. We've got quite a proud and useful cover to that bottom, in there. We've got the ability to do something interesting in this space which will get you upstairs.	Fc
346	Got a fully functional kitchen. Got an extra little back gallery area, so enough gallery space, storage, all sorts of things; and upstairs I've got work rooms and - so conceptually we really are there.	Fc
347	I'm happy with that.	Bsc
348	It was quicker than the last one. Wondering what else I need to do.	Nc
349	It does say reception; a big showroom; kitchen; bathroom; storage room - didn't do that particularly, but pfft; enough space. [0:55:03.9]	Rc
350	Well, this is laboratory conditions; don't spoil me.	Nc
351	Okay, does not need a garage, but it may be used for another function. I didn't do that; I didn't do the garage. These rooms should have a reasonable space [unclear].	Bsc
352	At the conceptual design stage the priority is overall house size, colour or material, but no furniture.	Rc
353	. I don't know what the colour is or material but - satisfy the brief and clearly represent the design concept in the form of 3D	Bsc
354	Okay, so the only thing I haven't done is basically the storage room, so I might just actually do that because I've got the time; and then I'm done.	Bsc
355	So a storage room would be useful down here.	Bsc
356	To work out how much room I need of the kitchen I can put in some objects which are useful to that, so kitchen cabinets.	Sc
357	So this is what CAD is useful for; I can lay out things.	Nc
358	Mirror straight across that line; mirror; straight across that line,	Sc
359	make a copy and drag the copy 1200 away	Dc
360	which is your ideal working space.	Bsc
361	Move that door over to here. Move that door over;	Sc
362	okay so now we've lost a window.	Sc
363	Move that door over to there. So now we've got a big cabinet on that side; the cabinet on that side.	Sc
364	We've got a wall there; got the wall there.	Sc
365	. I can't remember now if that was the existing one or not. No it wasn't, so I may as well do that, and now we've got an existing wall there; 1100 wide;	Sc
366	that can be our storeroom until we know what size we need.	Fc

367	There's always that as well, which can also be appropriated and some things can happen.	Nc
368	I might still leave that; put that to there, so there's a wall to be against, and I'll put another door basically in here.	Sc
369	So that's the storeroom, and it can probably be made into a cupboard or something anyway.	Fc
370	That's the storeroom; that's the kitchen; that's outside; and that then is a much nicer way of going outside onto something else.	Fc
371	So, okay, I think I'm done. Yeah, there's not much more designing I'd want to do on the CAD I don't think.	Nc

SMM Session: Participant D

NUMBER	**UTTERANCE**	**FINAL CODE**
1	Okay, okay, so I'm just going to read - I haven't read through the brief at all yet, so I'm not really too sure what I'm doing,	Ns
2	so I'm just going to read through the brief, so that will take me a couple of minutes.	Rs
3	What I might do this time is just pick out the relevant points	Rs
4	and write them down on the piece of paper, as I'm going through the brief.	Ds
5	Okay I've read through the brief and as I understand it's redeveloping an existing house, and it looks a typical bungalow house, a one storey house.	Rs
6	I picked out that it's actually she - or young family needs to redevelop it so it's two storey apartment, like I said for a young family with two children.	Rs
7	She's specified that she would like a bigger bathroom and also that the living room, kitchen, bathroom, garage, hallway, stairs are on ground level and there are two bedrooms with balconies on the first floor.	Rs
8	So I'm just going to familiarising myself with the existing design, it has two doors into the living area, small windows, not really looking out on to much.	Bss
9	Then on the left hand side is the staircase reaching up to the attic I presume.	Bes
10	On the ground floor, kitchen, small window and a door to the external I presume into the garden.	Ss
11	It has one bedroom again these are small windows and it sleeps one, there's the bathroom yeah it is quite small.	Bss
12	Nativity which is accessed externally.	Ss
13	Okay, so I'm just familiarising myself with what she needs. Living room, kitchen, bathroom, garage, hallway, stairs and garage.	Bss

14	Jeff, sorry, she says that she needs a garage, where is it, garage.	Fs
15	Garage.	Fs
16	Is that for a shed or for a car?	Fs
17	Oh just maybe put a little stuff maybe to someplace to put her stuff, we don't need to put a car.	Fs
18	You don't need a car, so it's more of a shed or something like that?	Fs
19	Yeah, yeah storage.	Fs
20	Yeah storage okay. Okay so I'm just kind of...I'm just kind of going through now, some orientation of where things should be.	Bes
21	Most families spend the majority of their time around the dinner table,	Fs
22	so I should be kind of I guess directly linked to the living area.	Bes
23	So I'd be tempted to put the kitchen, to take one of the walls down between the kitchen and sleeping area,	Ss
24	and to try and put the living and kitchen area next to each other there,	Ss
25	that's overlooking the garden area.	Fs
26	So I'm just sketching out some kitchen and living area.	Ds
27	So I'm trying to design a space that incorporates both these two and can overlook maybe a small balcony.	Bes
28	So I've put at the minute, I've put so the Bi Fold doors,	Ss
29	some kind of door system opens all the way out, which will open the kitchen, living room.	Fs
30	So the external utility will become the garage	Bes
31	so it doesn't take space up internally, so I'm going to call that storage [unclear].	Bss
32	Actually because of the - because we're taking out the sleeping areas, it's actually quite a vast area.	Bss
33	So I'd probably be tempted to have that kitchen	Bes
34	kitchen and so the top floor - the where the kitchen is, kitchen sleeping area, knock the wall down and have that as an entire kitchen.	Ss
35	So that could have the kitchen and dining area, kitchen and dining.	Bss
36	Then I'd probably - she needs a bigger bathroom she said,	Bss
37	so I'd probably take out the wardrobe in the sleeping area	Ss
38	and move the wall so it's in line with the utility - external utility wall,	Ss
39	and that creates a bigger bathroom.	Bss
40	I'm just creating a bigger bathroom now, I'm going to close the door from the kitchen, I'm going to have it accessed from the living area.	Ss
41	So that's bathroom and then living area. So I'm just putting maybe some	Ss

	windows on the - some of the doors where I think they might be used.	
42	So I'm creating an external balcony to the kitchen	Ss
43	and I think I'm going to create one for the living area too.	Bes
44	Because I don't know the location and I'm not really sure what the area is like if it's built up or if it's in the middle of a field, I'm taking it as it's quite open and expansive and perhaps in the middle of woodlands as well.	Bes
45	So I've put - instead of conventional Bi Folds between the kitchen and living,	Ss
46	probably just have these kind of doors that can open 90 degrees on both sides,	Ss
47	you can see on the plan it's quite hard to - to describe.	Bss
48	So in the living space I've created a wall louvered system	Ss
49	so then they can actually - we've got some cross ventilation all the way through from the living room through to the kitchen.	Ss
50	It also means, depending on orientation and north and all that business, that they can close the actually louvers to satisfy their needs during the day and during the evening, it's the difference in orientation during the summer and winter.	Bss
51	One thing that I'm not happy is that the bathroom kind of opens straight on to the living room	Bss
52	and I guess I could put some kind of porch	Ss
53	but that would get rid of this octagonal look I'm trying to achieve.	Ds
54	First floor is quite simple, as you go up the stairs, again [unclear] and I'd probably keep some kind of mezzanine.	Bss
55	So I'm just going two bedrooms with balconies, away and across the balcony so you can look down on to the open space	Ss
56	Two bedrooms, I guess the master - oh well I guess because there's two children in the one bedroom I guess the bedrooms should be the same size possibly, maybe the master bedroom could be a bit bigger.	Ss
57	Again these would be louvered system, again they can close and open as they wish for not only sun, ventilation, privacy issues.	Ss
58	I'm just trying to figure out where the orientation of the kitchen, storage.	Bss
59	Jeff can I go into CAD, do you want me to go on CAD, is that okay now can I just go straight in?	Nc
60	Yeah, yeah sure, sure, so yeah.	Nc
61	I probably would change a bit...	Bec
62	Yeah no worries you can change it.	Nc
63	but we'll see how we go okay. So do you take that now?	Nc

64	No, no.	Nc
65	You're taking my pad, you may as well take that one then.	Nc
66	You can keep those and those CD's yeah.	Nc
67	Okay so the first thing I'm doing is taking that whole roof off	Sc
68	and I'm just going to quickly move - start taking out the walls	Sc
69	that I don't need, which is basically all of them.	Bsc
70	I might just - actually I'm just going to make a copy of the house, just to see where I've got to.	Dc
71	Like I said I'm just taking out the windows	Sc
72	and certain elements that aren't going to be part of the design.	Bsc
73	I'm making the bathroom a bit bigger at the minute	Bsc
74	it's one point five metres, so we'll just see how much another one point five would be,	Sc
75	so three metres by three	Sc
76	that's too much	Bsc
77	I only need a metre, maybe a bit more half a metre.	Sc
78	Okay so now the bathroom has gone to two point seven by two point five.	Sc
79	So the door, I'm just going to, just making that central area now with the doors with the centralised doors.	Sc
80	I'm lifting everything by half a metre	Sc
81	I'm going to quickly put a slab underneath it.	Sc
82	So like the house will be made out of timber,	Bec
83	so I'm just changing the timber slats. Timber slats would go over the foundation so you wouldn't necessarily see, just increasing.	Sc
84	I'm just going to change the doors, they need to be double	Sc
85	and it needs to be made out of timber.	Sc
86	Garage doors. So I'm just trying to put these - the doors in between the kitchen and the living room.	Sc
87	So instead of two like on my drawing I've put three in.	Sc
88	Can't be too	Bsc
89	accurate because I haven't got time.	Nc
90	So I've got a feeling that this is going to look better on plan than in CAD.	Bsc
91	I'm just for some reason I've stuffed the doors.	Bsc
92	So I've put those - started putting their living room entrance doors in now,	Sc
93	then I'm going to put the slab in for the entrance porch or entrance balcony.	Sc

94	Starting to put the stairs in now, they're generic stairs so it's tread of 280 and possibly 155 for the rise.	Sc
95	So I'm just decreasing the stairs now to correct the [unclear] and like I said it is 150 rise,	Sc
96	and I'll just put three steps, yeah three steps.	Sc
97	Just taking steps away from the wall	Sc
98	might increase that it's a bit mean	Bec
99	I'm not really going to have much entertaining space	Bsc
100	increase it by three metres	Sc
101	then I can move them and centralise.	Dc
102	I'm just going to make some columns 100 by 100, I'm sure they'll be [unclear]	Sc
103	So just - just creating these legs for the porch	Sc
104	and for aesthetic reasons I might bring these in.	Bsc
105	These would be made out of timber too.	Sc
106	Just morphing - creating larger windows now for the living area	Sc
107	which would have the louvers on top of them.	Fc
108	Okay so now I'm just going to copy over the balcony or the entrance balcony	Dc
109	and I just need to create it to make it bigger so it fits with the same size as the kitchen.	Sc
110	Then it's just a case of moving the stairs, so they're on the left hand side	Sc
111	I might even - might get the stairs the same size I think.	Bec
112	I'm just adding some posts. Something weird with settings,	Sc
113	it's not quite the same, so I have to move some of these shortcuts aren't quite working.	Bsc
114	I really don't need that option. Okay that's good.	Bsc
115	I'm just putting the door into the toilet,	Sc
116	and just taking one from the original one I copied, that should be in there.	Dc
117	I'm just changing the surface internal surface should be white.	Sc
118	So that's just an extra window, the CAD systems a nightmare.	Dc
119	Jeff, is there a reason - this one, that wall there is two point eight, and this one here's three point one, so which one's right?	Sc
120	Because I've gone on to this one the two point eight, so I've somehow...	Sc
121	You can decide which ones they are sort of [unclear]	Nc
122	I'm looking at - attempt to put the louvers in, might be a bit much but may be part of this scheme.	Sc

123	These are going to look great, not really too sure what section they come out of.	Bsc
124	They come out of the wall, I can actually put one on angle.	Sc
125	I'm just - again I'm just morphing. It's crashed I think.	Nc
126	Maybe...	Nc
127	Has this happened before?	Nc
128	What?	Nc
129	Has this happened before?	Nc
130	No.	Nc
131	Just pause it?	Nc
132	Ok. I'm calm and bored at it.	Nc
133	[Laughter]	Nc
134	Ok … So I'm just concentrating on the deliveries of the minute.	Nc
135	I'm … so I just create deliveries that can be operated, depending on what the weather's like.	Fc
136	On the orientation on … wind circulation and orientation of the sun …	Fc
137	I have increased the bathroom, which is good.	Bsc
138	The carriage or the storage … it's the living room, dining kitchen which you can both open up on to the verandas.	Fc
139	I am just going to put the first floor in now, I think.	Sc
140	… also changed out the materials to timber.	Sc
141	I'm just thinking, I've drawn the location of the stairs on the left hand side of the room.	Dc
142	I'm just considering the thoughts… the best option.	Bsc
143	Now I'm just concentrating on the kitchen wall, so I can put the door in.	Sc
144	. I want the doors to be able to open out.	Fc
145	I'm just trying to see what the best option is in terms of …	Bec
146	I just placed a … I've just placed a slid-in folding door.	Sc
147	I'll just see if we're going to fit two … which we could.	Sc
148	Two fit in, which is quite nice	Bsc
149	Just see if we can go to that post in the middle …	Sc
150	I'm just going through the thought process of the roof.	Bec
151	On what kind of roof I'd like …	Sc
152	I'm just not sure of what roof would be the best option.	Bsc
153	Maybe I'm just going to put a slab into the first floor.	Sc
154	I'm just going to … I made a mistake here. [Hums? papam pupedu	Bsc

	00:0918] … Ok.	
155	Thinking of this distance it might be … better to overlook the kitchen.	Bec
156	It's quite nice to be [crosstalk 00:11:06] all the way through the house … and these … those are windows would be a lot more minimalistic	Bsc
157	Above view right through the house there, ok. … It'd be quite nice one.	Bsc
158	I'm not so sure as to which two were the … the first floor …	Bec
159	I've just given the balconies … just to see if I can …	Sc
160	I'm just separating the two bedrooms with the partition wall.	Sc
161	Certainly, I like my artist residency.	Bsc
162	I'm just increasing the … pebbles, so it gives me a first wall.	Sc
163	I'm just… fill the walls with the glass roll in.	Sc
164	Just doing some balustrade for the balcony …	Sc
165	Mine's a 900.	Sc
166	Again, I'm increasing the heights of these.	Sc
167	These walls all think up the first wall.	Sc
168	Guess I'm designing… I'm not going to long hand just now. Best solution?	Bsc
169	And through all this … I could count 16	Sc
170	I think I'll stick to my 15.	Sc
171	Let's put out a roof to the …	Sc
172	Turn the living room …	Dc
173	So I'm just caving the roof to the first floor.	Sc
174	Hello. Yeah, ok … so	Bsc
175	Ok.	Nc

SMM Session: Participant E

NUMBER	UTTERANCE	FINAL CODE
1	All right, going to analyze the brief.	Rs
2	Okay. Redesign the existing house into a two-four architectural office with three architects and one manager.	Rs
3	For three and one, so four people. You need to focus on architectural designs interaction with the space and its overall aesthetic appeal. Yeah.	Rs
4	The office design must use conversation tasks provided by the … yeah, yeah, yeah.	Fs
5	Okay, should include reception.	Bes
6	Okay, so we need a reception.	Bss
7	Oh no, what do I need?	Bss

8	Reception, meeting, kitchen, entry.	Ss
9	Okay, so two design rooms and a maintenance making it around two design rooms, open working area, circulation. All right.	Fs
10	Now, so [rustling of paper] basically the existing ground floor with internal walls and utilities. Okay, so a basic entrance is here.	Ss
11	Okay, so we want to put in a reception area so used to keep up to … all right.	Ss
12	Okay, so we can get reception through to here.	Ss
13	Make it a small maybe the entry comes through into a desk here.	Ss
14	Let's pushed further, here's a desk here and big spiral stairs and then an office there.	Ss
15	Spiral staircase in here.	Ss
16	A big void through here so internal void through here	Ss
17	and remove this wall.	Ds
18	Keep this wall	Ds
19	and remove this wall.	Ds
20	Make this … okay, keep or actually keep utilities, keep utilities.	Ds
21	Get rid of this one	Ds
22	and then small kitchenette on this wall, , so a kitchen here.	Ss
23	Now what else do we need.	Bes
24	Kitchen, bathroom, meeting room.	Ss
25	Okay, so then continue bathroom to stay here,	Ds
26	so bathroom and kitchen's there.	Ds
27	This entire [inaudible 00:05:13] in here becomes the meeting room.	Bss
28	Maybe we'll remove that wall	Bes
29	be glass	Ss
30	and you go there.	Fs
31	Okay, so now there's a course with a glass panel all around here.	Ss
32	Enter through here.	Ss
33	Spiral stair behind reception, so the reception seating off the side.	Ss
34	Okay, so reception, meeting, kitchen, meeting, reception, reception.	Ss
35	Okay, that could look out onto a cool terrace.	Bss
36	The terrace is the same.	Bss
37	The bathroom's pretty small anyway so it's good.	Bss
38	Okay, right-o, so then we go to ground floor.	Fs
39	Let me get these drawings up again.	Ds
40	The basic [inaudible 00:06:51] story I've got to work with. Okay, so, want a void across there	Bes

41	so there's a void here,	Ss
42	but we want to take those stairs off	Bss
43	and use spiral right here.	Ss
44	That might let you get off into this level,	Fs
45	so maybe the spiral across to there	Bes
46	and then get off onto here.	Bss
47	We've got, so that's all the way to there.	Ss
48	We've got all this open to work with.	Ss
49	We need to put a, so, maybe get out of here and there is a …	Ds
50	Okay, so now there's a veranda that runs all the way around and such.	Ss
51	That's a new veranda through there,	Ss
52	, circulation, circulation.	Fs
53	Then, this space becomes design room one,	Bss
54	DR1, and DR! and DR2 share the same	Bss
55	so now we've got an entry there.	Ss
56	This is the same, DR2, space there	Bss
57	Open courtyard.	Ss
58	Okay, so … sorry Jeff how long did I have until?	Ns
59	You have until 12:50.	Ns
60	12:50? Cool, cool. Okay.	Ns
61	Now, maybe I can create here …	Bes
62	I have already counted rooms and in here so we have our two separate areas	Bss
63	so there's a separate smoking over there.	Ss
64	We'll just type in [camry 00:10:22].	Ds
65	All right, so design room, courtyard, design room.	Ss
66	Maybe back room,	Bes
67	maybe stairs down	Bes
68	and that's looking out over there … view.	Bss
69	Sort of sliding away.	Ss
70	Two rows all glass.	Ss
71	Decked area here, deck right there,	Bss
72	got doors. Okay.	Ss
73	Okay, so new section perhaps … we've got a ground floor grade.	Ss
74	Let's say you walk in	Fs
75	and there's a spiral stair.	Ss
76	Say you walk in,	Fs
77	reception desk.	Ss

78	It starts to circle coming out like that	Fs
79	and all the offices look. Okay.	Bss
80	All right, so, I'm finished drawing	Bss
81	and I'm going to the computer.	Bsc
82	Right, now so my reception, doo, doo, doo, okay, now let's do this.	Bsc
83	Let's get rid of the roof. Get rid of the roof.	Dc
84	We'll start at the ground floor.	Bsc
85	Okay, so we want to … see what we've got here.	Bsc
86	Okay, so we're going to change this door to a sliding glass.	Sc
87	Okay, so, cool sliding glass door.	Bsc
88	See what that looks like in here. Yeah, okay.	Bsc
89	We're going to have a, block out that there,	Sc
90	so we're going to make.	Dc
91	We'll keep the utilities	Dc
92	but we're going to get rid of the existing kitchen wall.	Dc
93	The storage area so can get here.	Sc
94	Get rid of him. Get rid of him. Get rid of him.	Dc
95	Okay, so we'll leave that utility end and storage in there,	Sc
96	so well get rid of this door as well.	Dc
97	We're going to make it a small bathroom,	Sc
98	so we'll go ahead and make that the same length as that.	Sc
99	Okay, so we're going to make that the new bathroom.	Sc
100	Okay, give an internal sort of stool space there.	Sc
101	Yeah, that's pretty good.	Bsc
102	Create that. Okay.	Dc
103	So, the bathroom there from meeting room.	Sc
104	I think the bathroom needs access as well.	Bec
105	Okay, so functionally it needs to have access to the bathroom as well,	Fc
106	so perhaps we push this wall,	Bec
107	reduce the size of the main room to …	Sc
108	that's good.	Bsc
109	Make this sort of corridor off to the left,	Sc
110	so make an internal wall to section that off which is kind of	Sc
111	, yeah, it works.	Bsc
112	So bathroom, corridor, meeting room now becomes a bit small,	Bsc
113	but get rid of that, get rid of that.	Dc
114	Kitchen, excuse me, still sits behind there.	Sc

115	So now we just of bring this a bit further up.	Sc
116	Now, okay, so, turn this wall into,	Sc
117	okay, let’s get rid of that, yeah, leave that.	Dc
118	Okay, now we put in a. Jeff?	Nc
119	Yes.	Nc
120	Can you put in furniture to get space and then …?	Nc
121	Oh, yeah, yeah, yeah, sure, sure.	Nc
122	[Crosstalk 00:19:50] that’s from okay, cool. All right.	Nc
123	Breakfront, okay so we want to get our stair in place,	Bec
124	so we’ll get a staircase.	Sc
125	Screwy spiral one with the resultant spiral staircase.	Sc
126	Then, we’ll chuck it; put it in there,	Dc
127	that’ll work in there.	Bsc
128	So now, this big sort of centralized focus.	Bsc
129	[Inaudible 00:20:39], so on [inaudible 00:20:42]. We’ll put a little desk in.	Sc
130	Okay, table and I'm going to get a table, desk.	Sc
131	Okay, so I'm just going to put a note, furniture to and that might change.	Sc
132	Basically I'm pretty happy with down there,	Bsc
133	so let’s see now it works upstairs.	Bec
134	All right, so we want to put a slab in first.	Sc
135	Let’s copy the slab from the bottom,	Dc
136	so we know what we’re doing.	Bsc
137	Okay, so, we might, we’ll creat the major area right there	Sc
138	and then we’ll put a green dot around the entire [inaudible 00:22:18] of the … so, that’s 900 wide.	Sc
139	We have 900 wide.	Sc
140	So, that’s 900 veranda all the way around the outside.	Sc
141	Okay, so I'm going to make this cool green to go right to here.	Sc
142	Okay, so, I’ll put this, here you go.	Dc
143	This will be wall around here so let’s put an atrium space	Sc
144	which will look pretty cool.	Bsc
145	Okay, so this is going to be totally glass	Bec
146	and we’ll make it just blue glass	Sc
147	so you can see it.	Bsc
148	It’s going to have a check-in space,	Sc
149	right yeah, looking pretty cool.	Bsc

150	Okay, whoops. Undo. Hey, Jeff, it's doing, it's doing something. Not enough memory to … I think if I go back to here.	Nc
151	Uh-huh.	Nc
152	I'm going to try and undo that.	Nc
153	Uh-huh.	Nc
154	Hmm.	Nc
155	Ah, we’ve [inaudible 00:25:06].	Nc
156	No, that’s all right. So, I'm trying to undo what I did so it doesn’t do it. See if I can do it and [inaudible 00:25:25]. All right, there we go.	Nc
157	Okay.	Nc
158	Yeah.	Nc
159	Scary.	Nc
160	Phew. All right, so I'm going to have to use [inaudible 00:25:42], yeah which is all right.	Nc
161	Okay, so let’s move and redo walls,	Dc
162	so we can see in there [inaudible 00:25:53]. Okay, blue, okay.	Bsc
163	All right, so, we’ll extend our slab out to meet the cool spiral staircase that we’ve got.	Sc
164	Maybe you went up the spiral staircase towards the back of the room,	Sc
165	so we’ve got more space for lobby. Yes.	Bsc
166	Okay, so we’re going to extend this slab.	Sc
167	Okay, so, we’re going to raise that so it meets that.	Dc
168	Pretty cool.	Bsc
169	We want line that structure.	Sc
170	Okay, so that’s coming out to there, be back around the outside	Sc
171	I want to also put in, so we’re going to put in our new design rooms.	Sc
172	I’ll use an internal, say use that wall here,	Sc
173	but we’ll change it so we just make this cool.	Bsc
174	This seems a little crazy here by one, okay.	Bsc
175	Okay, so we make this one mirror. Yeah, we’ll make it mirror the existing structure.	Dc
176	We’ll cut it to there and make that one come across as well.	Dc
177	Okay. We want to put a drawing room 1 in here,	Sc
178	so we might actually even decide that mirrored over here.	Bsc
179	We’ll take that out to there, being it across so.	Dc
180	Cancel that	Dc
181	and just measure this first, so we want to come out 2,500 so we’ll go up to	Sc

	there.	
182	We'll go across 2,500 and go down.	Sc
183	Okay that I'm going to cross.	Sc
184	Yeah, it's looking cool.	Bsc
185	Yeah, so maybe split this deck,	Bec
186	so we're going to split, wherever the split is.	Dc
187	Is it right? Here we go.	Bsc
188	[Sighs] All right, [inaudible 00:31:41] I'm still looking for the tool to split the … there it is.	Bsc
189	I'm going to split that,	Dc
190	so I've got this to play with and that the play with good.	Bsc
191	It's going to turn it into a deck now while we're here just turn that whole thing into a deck.	Bsc
192	Have a check on the 3D.	Dc
193	Yeah, cool.	Bsc
194	Okay, maybe I might make the deck circular,	Sc
195	so actually we'll do that later. Okay, so we'll do.	Bsc
196	How many we got left? Twenty minutes. There's still … we will go.	Nc
197	Just stuck a few people in to make sure we're going through a couple design tables.	Bsc
198	Okay, now I'll allow that to be in the middle so we'll make it centralized.	Sc
199	No, perhaps not. Okay, just got to find the best to … so there's no [inaudible 00:34:18] at this stage.	Bsc
200	They've got a pass-thru.	Sc
201	Okay, so, we're going to put a little deck that's all shared terrace.	Sc
202	I'm going to raise that there,	Dc
203	so it looks a bit better.	Bsc
204	Deck is low.	Bsc
205	I'm going to use [inaudible 00:335:20] there, so I know that they are decking.	Bsc
206	Okay, so 24,	Sc
207	that's better.	Bsc
208	That's much.	Bsc
209	I'll change these to 100 and better extend that out and change that to design range [inaudible 00:36:11] right here.	Sc
210	Cool.	Bsc
211	I'll make you a wall. Wall setting, 100 again.	Sc

212	Bring out that wall to there.	Sc
213	Make this sort of the same happening here.	Bsc
214	Change that to 100, 100 not ten. You as well 100.	Sc
215	Good.	Bsc
216	I'm just changing all the, whoop, changing all the wall thicknesses so you've got that out.	Sc
217	Time check: 20 minutes.	Nc
218	Okay, so, make a little terrace again in there.	Sc
219	Looking pretty cool.	Bsc
220	All right, now let's put some doors in and we'll put some big double doors.	Sc
221	Just going to do drawing room one,	Dc
222	drawing room two.	Dc
223	Change this to 100 as well get it used to that.	Sc
224	We'll make some doors. We'll make some single doors, just normal doors in the middle.	Sc
225	Coming off that corner, we'll make them, 39	Sc
226	and it doesn't matter I'll make them smaller than that.	Bsc
227	Jeff, I don't know if this thing has stopped. Is it still going?	Nc
228	Yeah.	Nc
229	It's still going?	Nc
230	Yeah. [Inaudible 00:39:57]	Nc
231	Okay, now we're just going to flip the door so we want to do that.	Sc
232	Open again, that's better	Bsc
233	and change this one. Yeah. There we go.	Sc
234	All right. We'll have the same, we'll have a bit of a sliding door here I think.	Bec
235	I want a special door, sliding door. External sliding, external sliding.	Sc
236	I'll make it so it's pretty wide, even wider, 1,600 wide so it'll slide across there.	Sc
237	I need some more doors. Interior door goes into there.	Sc
238	ool. Okay, so, it's looking pretty good.	Bsc
239	It's going to turn, yeah; I can't really extend this radius so we'll just make it a meter.	Sc
240	Yeah, it's cool.	Bsc
241	A meter on this one as well.	Sc
242	Okay, let's see how it looks in 3D. Okay.	Dc
243	Jeff, I think it turned off again.	Nc

244	Oh, no.	Nc
245	Okay, so, good?	Nc
246	Yeah.	Nc
247	Okay, I'm just going to bring these doors down. Fix the doors up to … we'll do that.	Sc
248	Okay, so I'm going to refix the slabs.	Sc
249	Okay, I'm just going to go into 3D again	Dc
250	so we can pull these walls down. Down to 310, down to 310.	Sc
251	Adjust again, so we'll just view that. Back up to 300. Let's bring these in a ways.	Sc
252	Okay, so, that's all working.	Bsc
253	I'll turn this into a … see what sort of windows we can get.	Sc
254	Okay, get like that cool sort of paneling thingy up in here.	Bsc
255	Suppose that … we'll do that like that, make stained.	Sc
256	We'll make a doorway as well,	Sc
257	so I'll just put a doorway in there, oops. Go in here like that.	Dc
258	Flip that around, here we go.	Dc
259	I suppose we can extend that so it's a little entry and then we'll just whack in a boardroom table in our meeting room.	Sc
260	Okay, so meeting room, couches this, cabinetry, couches, sofas, furniture layouts.	Sc
261	Get a round one.	Sc
262	Get rid of these windows.	Dc
263	Extend this all the way across.	Sc
264	Private area there, kitchenette, meeting room.	Sc
265	I'm going to make some more windows in the bottom say three distributing [inaudible 00:49:16].	Sc
266	Let's check that out in 3D and do that.	Dc
267	Let's check the … we don't want that.	Bsc
268	We want that to zero. Okay. [Inaudible 00:49:57] away from this.	Sc
269	Huh? Not yet, nearly.	Bsc
270	Okay, we'll put the roof. Roof, brass roof, all right.	Sc
271	Okay, so we move this like that.	Sc
272	Really, entry and let's finish.	Bsc
273	Okay, so we're going to slightly to 800.	Sc
274	All right, so we need to go back down.	Sc
275	We're nearly finished.	Bsc

276	Okay, so let's slightly extend our walls. We can see, going, going, going.	Sc
277	Okay, so just finishing up the exterior materials.	Sc
278	Nearly done. Change that one to [inaudible 00:54:14]. Okay, so. Okay. Okay, nearly finished.	Bsc
279	Okay, so change that to this one.	Sc
280	Okay, bang, bang, bang. The entrance here, the entrance there. Glass, glass, glass. Nine King Terrace.	Sc
281	Ground floor being … [inaudible 00:56:12]. Can move that there and that there. Ask me to check.	Bec
282	Windows. We put just a few more windows in, some internal windows.	Sc
283	Fancy ones to look special. That's a cool atrium.	Bsc
284	A glass arch.	Sc
285	Okay, it should be done.	Bsc
286	Okay, so we'll adjust the height.	Bec
287	Measure height 2,300.	Sc
288	Okay, just going to put in a ceiling	Sc
289	and we're done. Okay. Mm-hmm. Okie dok.	Bsc

SMM Session: Participant F

NUMBER	UTTERANCE	FINAL CODE
1	I'll read the brief, I'll write down the bits and pieces, okay? All right, reading the brief.	Rs
2	Yes.	Rs
3	Sorry, what are the working rooms?	Rs
4	For staff, they are lack of their office, yeah.	Rs
5	Okay, so two offices upstairs	Rs
6	Yeah, yeah, two rooms for their work, yeah.	Rs
7	So two offices upstairs with a balcony?	Rs
8	Yes.	Rs
9	The gallery should include one big showroom?	Rs
10	Yeah, area.	Rs
11	Kitchen, bathroom, storage and upstairs there will be two working rooms?	Rs
12	Yeah, like their office, they do some - type, yeah.	Rs
13	Okay. Right, okay, thanks.	Rs

14	Okay, So I'm just writing my list in the corner of the paper, so gallery simply to reception.	Ds
15	Ground floor, one big showroom, exit on the gallery, so on gallery space. Gallery space, a kitchen, the bathroom and a storage room, stairs, upstairs two offices for staff.	Rs
16	Okay, put brief to one side, look at the template again. Looking at the template, seeing where I am. I'm just looking at the template.	Ds
17	Okay, so first sketch will map out what we have;	Ds
18	small sketch at the top marking out the areas that we have currently.	Ds
19	Okay, the first thing I want to do is find my gallery space.	Bes
20	So my gallery space - we'll start looking at the living room, because that's the biggest space.	Bss
21	The bathroom can stay the same.	Bss
22	Storage can stay the same and utility can stay the same.	Bss
23	So I'll work around that. Naturally the first place that can go is the sleeping space - that can go.	Bss
24	That wall can go, which is the main wall across.	Ss
25	That kitchen [0:05:00.0] can be a kitchenette again.	Bss
26	So we'll bring that wall in, just taking that wall across,	Ss
27	the main entrance there and a doorway there.	Ss
28	There we have our gallery space	Ss
29	and then the stairs can go there.	Bss
30	Okay. So take another bit of paper, lay it across that one.	Ds
31	Start to map this in, the utility, drawing my lines for the bathroom,	Ds
32	drawing in the bathroom walls and storage space.	Ds
33	I'm drawing the back wall all the way across, the door, the window, kitchen, main wall, door, main room there and that wall brought out to there.	Ds
34	So I've moved the living room wall - both living room walls actually.	Ds
35	That's the gallery - is there again.	Ss
36	Plenty of really nice light,	Bss
37	so I'll put a window there with clear Perspex behind it,	Ss
38	a big long window across the front.	Ss
39	Perspex behind that - sheets of, just - so white-in a three tall by 900 wide.	Ss
40	So more concertina level across that - one, two, three, four, five, six, seven, eight, nine - same with the back.	Ss

41	One, two, three, four, five - pull that in.	Ss
42	Then what we'll do is hang - a hanging wall in the middle that can be moved.	Ss
43	Okay, so we'll take that wall off.	Ds
44	So how long's that?	Ss
45	Stairs, kitchen, no - rub that line out.	Ds
46	Start by door there, stairs there, move the kitchenette there, a window in the kitchenette.	Ss
47	Okay, storage still there.	Bss
48	Bathroom; shading in the walls on the other side	Ds
49	a solid wall there and a solid wall there.	Ss
50	Kitchen, stairs and that's it and a hanging wall there.	Ss
51	Move that wall,	Ds
52	there's a heater and that wall can be the hanging wall too.	Ss
53	Light coming in from the north,	Bss
54	light coming in from the south;	Bss
55	north and south, I'm making it my north and south.	Bss
56	That goes upstairs.	Ss
57	So to simply go upstairs you have your smaller rooms	Ss
58	[0:10:00.0] sketching it against this space.	Ds
59	We'll start with a basic square.	Ss
60	Colour in now, de dah, de dah.	Ds
61	Now I'll get the atrium again,	Ss
62	an atrium like that.	Bss
63	So - hang on. Come back to this.	Bss
64	I'm trying to do the top floor.	Ss
65	So I'll try an elevation, a mirror, roof file in there,	Ds
66	two offices -one, two; one, two, a space in the middle	Ss
67	and just getting the mirror this time on top.	Ds
68	So draw another elevation of the roof next to the window,	Ds
69	tricky elevation.	Bss
70	A space there, a space there so screening roof, so back to the first sketch.	Ds
71	I'm just sketching over that where the two offices will go and thinking of taking out a large chunk of the floor here.	Ds
72	So you come up the stairs, the floor - you need a small passageway across the top.	Fs

73	So you have one office there	Ss
74	a big amount of light coming down. A big amount of light coming down,	Fs
75	a big atrium, split that - completely split it,	Ss
76	so that you can look at the front or the back.	Fs
77	I like it at the back, to the north, get all of the south light in and as much of the north light as possible.	Bss
78	Okay. Okay, I think I'm about ready to move over to that.	Ss
79	So I'll put that there, so I'll keep that in front of me.	Ss
80	Put that to one side and I'll start writing up what I've drawn.	Ds
81	Okay. I'll start with the bottom floor. Do it again.	Ss
82	I hide the roof. Just hiding the roof and now it's hidden.	Dc
83	Good, just double check that, excellent.	Bsc
84	Now, I'll start with my front wall.	Sc
85	Okay, I'm zooming in and I'm taking out existing windows,	Dc
86	shorten that to there	Dc
87	and copy it so I don't have to re-draw it.	Dc
88	Move it over and I will splice them together.	Dc
89	Now, I'll stick another wall in between those two,	Dc
90	move it down	Sc
91	and change the material to glass.	Sc
92	Blue and I'll make [0:15:00:0] it 10 mil.	Sc
93	Bring it down, select it, copy it, move it back and I'll make that - Shift-R	Dc
94	- 900 long and exit.	Sc
95	Now that is - that's going to be my Perspex light diffuser.	Bsc
96	So I'll make that opaque.	Sc
97	Looking at my materials - I'm looking for my materials.	Sc
98	I'll just make it paint,	Sc
99	because we know what it is.	Bsc
100	We can move, multiply them and distribute maybe	Bec
101	well, one, two, three, four, five, six.	Sc
102	No, I won't.	Bsc
103	What I'll do, I'll actually angle that from there to there,	Sc
104	zoom in, yes, now I'll move it there.	Dc
105	That's it.	Bsc
106	Multiply, maybe make six of those	Bec

107	zoom out, drag them across and there we go.	Dc
108	Okay, now I'll do the same with the back wall,	Bsc
109	yes, because I'm getting rid of all of that and that is going.	Dc
110	just orienting myself to what I did and I'm taking out - based on the sketch that I did - all the internal walls.	Bsc
111	So that can come out and that can come out.	Dc
112	move the door at the back.	Sc
113	I'll soon get rid of that. Get rid of that window first,	Dc
114	move the door across,	Sc
115	get rid of that window, get rid of that window,	Dc
116	move my wall all the way across to there	Sc
117	and I'll copy and paste the first wall I did,	Dc
118	which was the glass wall with the opaque louvers behind.	Sc
119	Okay, well, I'll pass that then;	Sc
120	good.	Bsc
121	Come on. Keep, keep and keep and keep. Okay. Control paste, zoom out, look it up.	Dc
122	Control - I think it's Control-E to rotate and place.	Dc
123	Okay now, the ground floor is done and I put in the moveable walls.	Sc
124	[0:20:00:0] Okay. Down the stairs obviously, near all - I want spiral stairs - yeah, spiral stairs.	Sc
125	Get rid of that	Dc
126	move my wall, move that wall across	Sc
127	down to the first floor, so first storey same again	Bsc
128	Drew it all	Dc
129	I like my roof layer, okay.	Bsc
130	Put in my sealer, pay my slab, okay	Sc
131	Hang on, that could go all the way up.	Sc
132	Yeah, right, okay.	Bsc
133	Just put in a note for my slab,	Sc
134	so I can cut out the whole four stairs,	Sc
135	moving my stairs across and the same thing with the other node.	Sc
136	Bring that out to meet the stairs, so we have somewhere to go and now open up another node there.	Sc
137	What I'll do is I'm going to bring that in and that down to there, okay.	Sc
138	I put my slab across there,	Sc
139	make this one six metres,	Sc

140	make the bottom two metres.	Sc
141	Okay, we have five.	Sc
142	I'll bring the roof back and see where we are.	Sc
143	Okay, solid. Add them in operations, so there's a target, that's a shooter, execute.	Nc
144	Okay. Go to - I'll trial it now.	Bec
145	Make a new layer, so I'm in, okay.	Sc
146	Hide it, okay.	Dc
147	That goes on there like that.	Sc
148	Want to arc, go into file, all right	Sc
149	Now, Control-L, bring that back so I can see it. Just move it out - wonderful.	Sc
150	I'll try that. Re-hide the layer, click okay, there we go.	Dc
151	So now I will extend all of those up	Sc
152	so I go back to the ground floor.	Sc
153	Select manoeuvres; make them much higher, 200, 200, 500 - 600. [0:25:00.0] Okay.	Sc
154	Select my last panel, make that, right. Enter and got to the 3D view and see what that looks like.	Dc
155	Right, two de-selected. I'll go back and see what that's like.	Dc
156	Okay, cool.	Bsc
157	Okay, now I'll do my first storey.	Sc
158	Put my back wall in here; put my other wall in here and my other wall in here	Sc
159	Now, we'll go to 3D and see what that looks like	Dc
160	- awful.	Bsc
161	Okay, I'll have to trim that roof up. I'll have to trim that roof,	Dc
162	too much roof, so I'm back on my roof tool, shell roof up okay.	Bsc
163	I don't like that at all.	Bsc
164	I'm looking for a decent roof. Looking for a decent roof;	Bec
165	my roof tool, I just want one, here we go - and there we go.	Sc
166	Select type of roof and I want to select this way	Sc
167	so I go from here to here to here to here to there	Sc
168	and see where that is; excellent.	Bsc
169	Now, I lower my roof.	Bsc
170	I lower it, so I will fix the angle and raise the back side,	Sc

171	so I haven't got there - and I'm just fixing it - not over with my roof at the moment.	Bsc
172	So I have to move that up;	Sc
173	excellent.	Bsc
174	Fix the angle again,	Sc
175	but - no. I don't know why - can't I get the right angle?	Bsc
176	Thirty-eight, it's only five. Okay	Sc
177	Up a tiny bit and fix the angle;	Sc
178	excellent. [0:30:00.0] I'll find where it is, here we go.	Bsc
179	So move it out a bit that way, out a bit that way, out a bit that way and out a bit at the front.	Sc
180	Go back to that and trim all these walls to that roof.	Dc
181	I'm cropping everything to the single plain roof.	D
182	Going back to the plan, I'm just moving this back idle, putting in those	Sc
183	- I'll leave that open plan. Putting in a wall there	Sc
184	okay, quite a small wall	Bsc
185	and another wall over there.	Sc
186	Okay, we'll get back to the 3D view	Dc
187	Phew, lower that wall; lower that wall right down to there.	Sc
188	I don't see amount, hold it. Now, I'm just going to go to view, spin around.	Dc
189	I might delete that back wall.	Bec
190	I'll go to the plan. I'll go to the ground storey and raise those louvers five metres, enter.	Sc
191	Can I get back;	Bec
192	excellent	Bsc
193	Make that five metres too	Sc
194	just lower that, lower that and	Sc
195	then I might do this so they're all trim to the roof.	Dc
196	I'm done	Bsc

SMM Session: Participant G

NUMBER	UTTERANCE	FINAL CODE
1	All right. So I'm reading the design proof first, so two-floor dream apartment design. [Unclear] design to existing house [unclear].	Rs

2	For young family, one child. More space for the bathroom. Living room, kitchen, bathroom, stair	Rs
3	Okay. I'm first going to measure the dimensions to know how big it is, to get an idea.	Ss
4	Can I just ask one thing? The orientation would be north here?	Bss
5	Yeah. North, yes.	Bss
6	Okay. The current layout isn't the best orientation, so it would make sense to bring the living room up north somehow,	Bss
7	which is difficult because of the layout of the house shape.	Bss
8	So it might make sense to bring it somewhere into this area here, level.	Bes
9	Possibly move [unclear] somewhere here.	Bes
10	Possibly placing the stair inside into the middle somewhere.	Ss
11	Increasing the bathroom	Ss
12	and bringing the kitchen down here next to the bathroom.	Ss
13	This brings probably the entrance into this area here.	Ss
14	Orientation wise, the upper level, and so the stair sits here.	Ss
15	Orientation, windows towards the north which suggests to have possibly [bat] ones like that, and the roof terrace.	Ss
16	So how can the stair sit there?	Bes
17	[Unclear] five on five, yeah. Stair. Kitchen.	Ss
18	You need to talk.	Ns
19	Sorry?	Ns
20	Talk, talk.	Ns
21	I need to talk, sorry. I'm sorry.	Ns
22	Okay, so I think the bathroom size would be okay	Bss
23	and in this location the kitchen size could be like that.	Ss
24	Now, at the moment I'm thinking of how to place the stair so it makes sense downstairs for the entrance situation and upstairs.	Ss
25	The rooms should be probably divided	Bes
26	but the kitchen is a bit smaller.	Bss
27	The stair sits somewhere towards the kitchen and towards west there will be a larger space.	Ss
28	This would indicate that probably this becomes the master bedroom	Ss
29	and this would be the bedroom for the child.	Ss
30	So coming from here it makes sense to move up.	Ss
31	It's probably a U-shaped - stair might be useful.	Ss
32	How much space do I need?	Ss

33	If this will be the line up here, you can walk in.	Fs
34	Here it should increase more, as what it would be here.	Bs
35	So I would have - [as to how] to have a longer flight that starts somewhere here, and moves up here	Ss
36	Here underneath could be bookshelf or so, storage.	Ss
37	Let's extended cupboards so it looks as if the kitchen just runs across	Ss
38	and let's have dining here, no walls, perhaps if desired only a small change.	Ss
39	This would be the living area.	Ss
40	So it leaves this area for the entrance, so that would be…	Ss
41	…the wardrobe, small storage underneath and the entrance door.	Sc
42	Free [unclear]. [Unclear] level. Okay, so I set up the storeys.	Sc
43	I leave the ground level as it is in the height	Sc
44	and I change the height for the upper level.	Sc
45	Basically take out the doors and most of the existing windows.	Sc
46	So I take this wall as orientation.	Sc
47	I stretch this one across.	Sc
48	Indicate this as bathroom.	Sc
49	Place a wall right here in between and take this as adjustment to continue the bathroom, has plumbing, mechanical.	Sc
50	Family friendly bath [cube].	Sc
51	So there would be a door finally.	Sc
52	I place a kitchen, or indicate. Place the door somewhere here.	Sc
53	So I have created just a normal opening,	Sc
54	basically - wrong,	Bsc
55	I have to move it until here to create space for the stair,	Sc
56	which will simply sit like furniture between the living room and kitchen.	Sc
57	So I have to think of a stair and I would like to create something like that, though it would be [free one].	Sc
58	That should become longer, possibly.	Sc
59	Okay, too big	Bsc
60	Let's limit to 890.	Sc
61	This should be also different, flight would be - it can be less.	Bsc
62	Yeah, I see. One metre,	Sc
63	it should be more, so there should be [unclear]. Okay.	Bsc
64	Possibly I would simply take this out,	Dc
65	scratch it	Dc

66	because it's very large.	Bsc
67	The stair still takes quite a space.	Sc
68	I could move it but however a sort of wardrobe would also make sense.	Bsc
69	Okay, I do that.	Bsc
70	I keep this cupboard thing and simply drag this [unclear],	Sc
71	basically. Yeah, I can change this to one more, that's 12 or 13.	Sc
72	So I can still drag it a little.	Sc
73	Why can't I see what I'm doing?	Dc
74	Okay. So there would be a sort of wardrobe also. This would be split.	Sc
75	So the openings would be here all across, glass.	Sc
76	Okay. Here could be also the same window, basically.	Sc
77	The kitchen could get a small opening in between, possibly in a height in between.	Sc
78	I leave it for now.	Bsc
79	So the upper level would be -	Bec
80	first of all deleting the roof	Dc
81	and basically copying and pasting on this side of this thing here.	Dc
82	To the next [unclear] to then take out the objects.	Dc
83	The stair arrives,	Sc
84	this wall won't be there.	Bs
85	Why can't I see what I'm doing?	Dc
86	Okay, upper level.	Sc
87	Okay, I have a problem, it does not draw walls for some reason. I can't see what I'm doing.	Nc
88	If I want to place a wall it does not show me anything. So I don't know what it is, but yeah.	Nc
89	That's really [unclear].	Nc
90	No, no, I can't place.	Nc
91	If I would place a wall now - now it works for some reason, I don't know what it is. Oh, now it works.	Nc
92	Thank you.	Nc
93	But it - no, it doesn't.	Nc
94	So it's - okay, [unclear].	Nc
95	Okay, now I see the issue.	Nc
96	So I have to flip it again	Dc
97	Okay, back. I need more space upstairs	Bec

98	so I can't do this here, but I have to place the wall in a different way so there is still some space for this room here.	Bsc
99	So I have to turn these walls back into this here.	Sc
100	What was it, [29]?	Nc
101	Okay, so this could become the children's room	Sc
102	but I still need to flip the stair, give it more space.	Sc
103	So you could set a wall basically here.	Sc
104	So there could be a wardrobe here for the one room	Bec
105	and a walk-in robe for this one.	Fc
106	So I said I would basically pick that out here and doors would sit here.	Sc
107	Oops, it stretched [unclear].	Dc
108	There would be also windows all over the place,	Sc
109	So now I just try to place a roof,	Sc
110	so I have to first increase the wall heights to whatever it should be.	Sc
111	[Unclear]. Then I place a roof [unclear]. Zero, okay	Sc
112	and I need to trim these walls to roof, okay.	Dc
113	Once again I select all the walls, beside of the roof terrace railing, to change the material simply to something timber-ish,	Sc
114	but the material choices aren't many here and I won't create a new material right now.	Bsc
115	I simply select this here perhaps and hope that it looks [somewhat] good.	Bsc
116	The colour isn't so nice but I leave it as it is now. I think I'm finished.	Bsc

SMM Session: Participant H

NUMBER	UTTERANCE	FINAL CODE
1	Well, we can easily make the bathroom bigger.	Ss
2	We don’t need to … we don’t need the bedroom downstairs.	Bss
3	We can cut the bedroom downstairs out	Ss
4	and make a larger bathroom	Ss
5	we can cut the bedroom downstairs as to make a larger bathroom, but that gives us problems with the access to the utility room.	Bss
6	Maybe we got to move the access to the utility room across.	Bes
7	We can hold on a living room …	Ss
8	We’ve got to add a garage as well. Okay. We’ve got to have a garage as well.	Ss
9	Heavens knows where I’m going to put the garage.	Bes

10	Okay. Using the existing floor space, if we put … Now let's try to put downstairs	Ss
11	that we'll cut for the garage downstairs,	Ss
12	that would be helpful.	Bss
13	Extend the bathroom.	Ss
14	Get rid of the bedroom downstairs.	Ds
15	Probably have to enlarge the utility room.	Ss
16	Basically, I'm leaving the plumbing where it is.	Ss
17	Maybe, I'm not sure that's a good idea, though if I did that, I could change a single car space	Bes
18	If I change the plumbing … can I change the position of the plumbing? Can I change the position of the plumbing?	Bes
19	Okay, that's good, that's good. That makes it better	Bss
20	because that's already the shape of the garage.	Bss
21	We could actually make what was the utilities room and the bathroom into a garage.	Ss
22	If we did that, we've already got that shape there.	Bes
23	This is what that … changing the shape	Ss
24	Okay, that leaves us there.	Bss
25	Now, over there you need to walk in … if you don't want to walk in, in the …	Fs
26	Right, the kitchen should be next toward to the car port	Bes
27	because you'd be carrying the groceries in, you want to come and dump them straight in the kitchen,	Bss
28	so the kitchen should be on that side.	Bes
29	Then we can replace the bathroom either on the other side and make it larger.	Bss
30	Okay. I want a decent size bathroom.	Ss
31	Not bit, that's a very big bathroom.	Ss
32	We're going to have a utilities room too.	Ss
33	We want a large bathroom. We can have a utilities room that goes off.	Ss
34	Okay, we've got to have … We do that, we still haven't got a utilities room I hope.	Bes
35	We can have a kitchen there that would make a nice large kitchen.	Bss
36	Okay, we can make that a bit ... Okay. We can bring the kitchen over here.	Ss
37	We can have the utilities room because door needs to be small, but that still gives us …	Ss

38	Oh, does it give just a bigger bathroom?	Bes
39	Okay, we don’t have to have a huge bathroom.	Bss
40	A pen … a rubber. Good, I need a rubber. Okay. Okay, the utilities room has got to open into the kitchen, otherwise it’s too much hassle,	Bss
41	so is the car port. It’s got to open into the kitchen otherwise we don’t want to be carrying groceries.	Bss
42	The bathroom, a large bathroom beyond this side.	Ss
43	That keeps all the plumbing on the same side which probably makes it a bit cheaper, cheaper.	Bss
44	We leave this big great living room area where it is,	Ss
45	because it’s quite a nice area.	Bss
46	Get rid of those miserable little windows.	Ds
47	I hate miserable little windows.	Bs
48	That gives us a much bigger bathroom,	Ss
49	a little bit of bigger utilities,	Ss
50	same size kitchen,	Ss
51	access from the kitchen to the utilities and to the garage, and of course to the living area.	Fs
52	Okay, living area we got here. I think that’s about right.	Bss
53	That’s the garage on this side, kitchen, bathroom, utilities and living.	Ss
54	That’s coming with okay. I might make a little adjustments to that.	Bes
55	We still have more that we want the stairs.	Ss
56	Let’s look up the stairs. Now, upstairs, basically I’ll turn this into … we’ve turned this into the plumbing section.	Ss
57	Plumbing is along this side.	Ss
58	Does that work from upstairs?	Be
59	All right. We got to put a balcony up here too.	Ss
60	Okay, I’m going to put a balcony because we’ll have the main …	Ss
61	I don’t want a big bathroom there.	Bss
62	We could divide that because this is an own suite, it doesn’t have to be huge.	Bss
63	We could divide that there, we end up,	Ss
64	and we can have one bathroom that way, and we could have the veranda over on this side.	Ss
65	We could have actually a veranda right around.	Ss
66	Would that look good?	Bes
67	I don’t know if that might look great for him.	Bs

68	At this stage, we’ll have a veranda right around along two sides.	Ss
69	We still haven’t got up, have we? We might have to have a hole.	Ss
70	I hate holes.	Bss
71	We might have to have some way off getting to these two rooms.	Ss
72	We’ll have to have the hole here.	Ss
73	That’s dreadful,	Bss
74	that’s going to mock it all up isn’t it?	Bes
75	Stairs differently mock things up.	Bss
76	Okay. Okay, well we got it over here.	Ss
77	We got to go back to the bottom floor because we haven’t got the stairs, unless we fly upstairs.	Bss
78	I mean it’s a good floor plan to the bottom as long as you don’t want to slip away.	Bss
79	Maybe we can just change. What we can do is change the … change the front door.	Bes
80	We don’t want the front door there.	Bss
81	We will have the front door or we could have the stairs on.	Ss
82	We’ve got to have the stairs some way	Ss
83	Now if you put the bathroom on that which solves your problems downstairs,	Ss
84	it doesn’t really solve them upstairs which is a bit of a nuisance.	Bss
85	We’re going to have to ship the front door,	Ss
86	get rid of that door on this side	Ds
87	put the stairs there on a note	Ss
88	the stairs I have, I would go for a spiral staircase,	Ss
89	but maybe I shouldn’t this time.	Bes
90	Okay, which gives us upstairs, we’ve got the spiral staircase here.	Ss
91	Now how does that work?	Bes
92	Well, it might work well. That works terribly actually.	Bss
93	Okay, we’ll put the stairs in	Ss
94	we’ll get rid of that door.	Ss
95	We’ll put the stairs there which comes up to the topic.	Ss
96	Now, we’ve got the plumbing on there, we’ve got …	Ss
97	We need some way of make it up there, but this already a huge bedroom.	Bss
98	We can’t cut that down a little bit.	Bss
99	We’ll have a landing, and we can make that an L-shape	Ss
100	because we don’t really need that.	Bss

101	I quite like L-shape rooms, they give you room for cupboards.	Bss
102	Maybe you can just … Can you get rid of that?	Bes
103	If we do that, we've got a long way from the garage to go to the kitchen.	Ss
104	If we do that, we haven't got a very satisfactory bedroom	Bss
105	and we want two bathrooms at the on-sweep or do we need two bathrooms? Do we need two bathrooms upstairs all up in there?	Bes
106	It really [inaudible 0:12:56] to maximize your room, otherwise we've got more there, that is …	Bss
107	Okay, we're going to have on suite one into this bedroom.	Ss
108	On suite two to that bedroom, so that's a bathroom, that's a bathroom.	Ss
109	We're going to have three bathrooms in this house, so they cannot complain about lack of bathroom.	Bss
110	We've got out a large room here,	Ss
111	a staircase that goes up into here which can let you into this room here,	Fc
112	and which capes that square.	Sc
113	They're both very large rooms. Do you need such large rooms?	Bsc
114	Probably not,	Bec
115	but that will cut that over, over there. Into that room there	Dc
116	then veranda all the way around	Sc
117	because I like a veranda that goes all the way around. Okay, I do not think it's a break fit to design.	Bsc
118	Jeff: You set this by to join in all this …	Nc
119	speaker2: Probably not, but I'll work it out. (Laughs)	Nc
120	Jeff: I don't know if they got to take upwards.	Nc
121	Stairs are always problematic they take up too much room.	Bsc
122	I'm trying to make a lot of … maximize the room.	Sc
123	Okay, let's get rid of that.	Dc
124	Let's bring it over here, okay.	Sc
125	What we're going to do now. I'm happy with the downstairs, but not very happy with the upstairs.	Bsc
126	I'm not sure it's going to work very well upstairs,	Bec
127	but anyway, we'll firstly get rid of this miserable little doors and windows, just doors in here.	Dc
128	Get rid of the bathroom.	Dc
129	Okay, that's the garage. Right, that front door just going to go somewhere else	Sc
130	because I don't like it there, haven't worked out where it's going to go.	Bsc

131	We'll just cut and paste that upstairs first, copy.	Dc
132	Okay, we've done that. Now we've got to … Upstairs just strength of the slab so we can … just link them. Link them to walls.	Sc
133	Link in the walls, but I think … Aw, damn what happened there? I'm not going to change the Greek white, break it, no I don't like it	Bsc
134	because you haven't got enough materials.	Sc
135	I'd never choose white Greek.	Bsc
136	Oops, okay just getting rid of the gap between the top floor and the bottom floor.	Dc
137	Minus 300, okay.	Sc
138	Okay, we got rid of that gap	Dc
139	so that it looks a bit better than [inaudible 0:17:45].	Bsc
140	Okay, go back to our first floor. I haven't decided with the front door yet.	Bec
141	We'll first mark around here with that.	Dc
142	We'll move the spool across we're going to make that smaller.	Sc
143	I'm just reducing the … moving the kitchen toward over, wall over a bit more so we could and brace in a bit large kitchen.	Sc
144	When we could have another wall over here which is, on an 80, I'm just leaving the settings as is.	Sc
145	Okay, turn that over. Right, I think that's the only thing I have this on, it is in the right place.	Bsc
146	Right, we'll make a utilities room which is long and thin, can also be opened from outside.	Sc
147	We could actually put the shower raises in there that would give you a lot more room.	Sc
148	Could you done in such a big utilities area?	Bec
149	We'll make that … just that corner a bit, a shower raises.	Sc
150	Okay, so that gives you a shower raises tucked in a corner and the bathroom and that's the shell.	Sc
151	Okay, that's the bathroom, the kitchen, the garage, the living room. Okay, downstairs is okay.	Sc
152	Okay except we've got the problem of the stairs.	Sc
153	I haven't really … just a little of those windows because I hate the perky little windows and then I like perky little windows.	Bsc
154	Okay. We're going to the staircase in the corner here.	Sc
155	I don't know what sort of staircase I'm going to do. That's what I haven't decided. Let's go for staircase … I'm going to resolve the stairs first.	Bsc

156	We don't want a very big stairs.	Bsc
157	I got the right height.	Sc
158	I don't know whether that would be a very good one actually.	Bec
159	It's too big, too big. The staircases are far too big.	Bsc
160	Try another one. I'd actually make my own if I had time.	Bec
161	I don't like the … don't want the stairs again. No, I don't want that.	Bsc
162	I want to create a stairs. I'm going to find something that's small.	Sc
163	That might work. That might work, yeah.	Bsc
164	Okay, I've got a little bit of an L-shape on.	Sc
165	They're not obviously and awfully large to me, but I'll take it that this is standard measurements.	Bsc
166	That's not good. The stairs are proving to be problematic.	Bsc
167	Owning I'll go back to the old and make it a small one.	Scc
168	You have to have something a bit better than that, that's not going to work.	Bsc
169	Make it smaller, I mean it's just too big. I do not need such a big staircase. Still too big.	Bsc
170	Nice staircase needs to be that big. The staircase is problematic. I'm trying to maximize the space and I still haven't got it right.	Bsc
171	I'll try to think of another staircase.	Bec
172	If we try this one, it looks huge. No, that's even worse.	Bsc
173	Okay, the stairs are proving to be a stumbling block here. Oh, go away.	Sc
174	The stairs are those, try those.	Sc
175	That looks smaller. Okay, that looks a better size, but I have no idea what that looks like. I'm picking this purely on size, I will have a look.	Bsc
176	You got to maximize the space here. Otherwise we're going to end up … where does that get us to?	Bsc
177	Now, what I would do if I had a lot more time is I would create my own staircase where it takes up less room.	Bec
178	Oh, yeah I like that staircase. It's kind of jazzy, but it's kind of floating,	Bsc
179	let's attach it very closely to the wall.	Sc
180	It's a bit of a jazzy staircase, but not ideal, into the wall. Probably pretty dangerous, but anyway. (Laughs) I don't think we can have a dangerous staircases for the job.	Bsc
181	Let's have another look. One more try.	Bec
182	I'm still unhappy with those stairs. Now that could be a possibility. Okay. Now this could be a possibility, still too big.	Bsc

183	I like to resize it just a bit. I'm going to shrink it a bit.	Sc
184	It is way too big. Damn it.	Bsc
185	Let me shrink it while you're doing this. Turn it around.	Sc
186	Okay, now that is going to take up too much space. Oh God, I hate the staircase.	Bsc
187	I'd go back to the sparrow.	Sc
188	I hate staircases, there are always problems.	Bsc
189	Okay. Now, we'll pick a staircase. Okay, it's not ideal. I don't like it much.	Bsc
190	I'll go turn that around a bit so that it actually comes … I'll go have it facing the …	Sc
191	Otherwise, that won't work upstairs.	Bsc
192	That will do. All right, move it into the corner.	Sc
193	Just to turn it back a bit, lacking around party much for the staircase.	Bsc
194	Okay, that looks better and just isn't this all and wise, it's a bit more symmetrical, but still too big.	Bsc
195	Let me have a look in marquee up, it's already in the marquee.	Dc
196	It's a ghastly color but it will have to do.	Sc
197	but it will have to do.	Bsc
198	Okay, okay it doesn't even paint anything, then we still could have that door there, probably won't.	Bec
199	Okay, let's go up a floor and cut that out flat.	Sc
200	Do we need … ? Okay. It could actually … We don't need such a big hole with it.	Bsc
201	We'll just go up there. Okay, minimize the holes, so we're not waiting into too much trouble here.	Sc
202	I hit the slab. Didn't know how minimal would need it, but let's try this.	Dc
203	Okay, before you mock around with that. You will have to bring that over view pole.	Sc
204	Just moving the staircase a fraction over … I don't know that much.	Sc
205	Okay, now we just got to fix up that hole in-line with that.	Sc
206	Don't think anyone's head will crash there. Just make that hole much widely.	Sc
207	I won't knock around it with it too much, but it's about right now.	Sc
208	Is it okay that elastic will give it?	Bec
209	All right, okay it doesn't take up hips and hips of room.	Sc

210	We definitely improved that. Okay, let's go straight to the top floor. Oops not. This one. Okay, what we're going to do right now, I forgotten.	Bsc
211	Oh, that's right, we can have a balcony.	Sc
212	We are going to change the top floors.	Sc
213	We're going to have a balcony all around, so we're going to get rid of this wall.	Dc
214	What was I … ? Yes. Is that what you want? This out here, this out here. Okay, now we've got to get rid of these walls and put in some walls.	Dc
215	Now, I think I should look at that 3-D. Oops, full 3-D. Hold on and three screens.	Dc
216	Okay, it looks okay.	Bsc
217	We just have to move that out a bit all right, and we can to bring the veranda out the front.	Sc
218	Okay, we're going to have a bit more of veranda all round.	Sc
219	It's got to come a bit more, that's going to come up a bit more in-line, this and that.	Sc
220	We can still put that front door there now.	Sc
221	Now I'm not sure that's a very big enough veranda, except we could go a little bit bigger. I don't know how big is it.	Bsc
222	It's measure with measure. Oh no, fatty small.	Sc
223	That's easy if you can pull that out.	Sc
224	Now, we might leave that, walk that around because we got more … Make it because it has a front, we can't do that, but we can bring it out at the back.	Sc
225	Let's have a look.	Dc
226	There, that's better. Not huge, but big enough. We cannot have very large balconies everywhere.	Bsc
227	Okay, let's straighten that up, it's a bit crooked. Just give it tad while we're on that side	Sc
228	Putting lay all in here, get rid of those perky little windows.	Dc
229	I hate perky little windows.	Bsc
230	Put in the wall there. Now, you can actually shrink this bathroom up the top a little bit because this is on suite [inaudible 0:41:07],	Sc
231	you need to be too huge to get that bedroom a little bit more room.	Bsc
232	Divide that up.	Sc

233	Now, is that a paint you want on a wall? You just might have seen all. Heavens, what is that? Well always the wall … Okay, we want a thin wall.	Bsc
234	All of these settings are different to mine. I just want an ordinary wall. I hate these settings. That’s it, nice in every wall, okay.	Bsc
235	Where the hell is the imaginary wall in this? Oh, God. Get that partition. That will do, God. Now how big is that? How big is that bathroom? It looks too small.	Bsc
236	Okay, we shrink that up, we make it one bathroom.	Sc
237	The main bathroom doesn’t have a bedroom. It’s got to go downstairs. We can always put them both through and through. Okay.	Sc
238	Otherwise, it’s too small and I don’t want a big bathroom. All right, okay. Well I think that looks okay, right.	Bsc
239	We’ve got to make a hole here somewhere.	Sc
240	Get rid of those windows too.	Dc
241	Staircase is always stuff I have a plan if you can possibly think.	Bec
242	Okay, you’ve got to put … You’re going to have a large landing there.	Sc
243	The landing can probably open up into that because that’s quite wide.	Bsc
244	Okay, a door. That’s not going to work. It doesn’t give you enough room. I don’t know, I think you’ve stop this hope up there by trying to get no more. No, its okay, I think like that.	Bsc
245	Okay, we want slide doors, hope its back and find them. Its old doors. Simple doors.	Sc
246	Now, I don’t want simple doors.	Bsc
247	There’s no libraries. There’s no libraries to do anything. Doors. Slide doors. These are terrible doors. Now with ordinary slide doors.	Bsc
248	What? Heavens, I’m just trying to get … I’ll get rid of that then.	Dc
249	I’ll try that again. Oh, damn it. That slide doors, where are they?	Sc
250	Doors. I’ll have that one. Okay, that’s okay. All right, we got the outside shapes okay now.	Bsc
251	Okay. I don’t know where that wall came from. Okay. Now, let’s try and get in some other doors if I could find any. I don’t want slide doors and they’re not very nice.	Bsc
252	There’s no doors. Ankle doors, slide hinged doors, rotating doors, slide doors, but they’re not slide doors.	Sc
253	Where is the basic window even?	Sc
254	Look. All these doors are dreadful horrible doors and I don’t like any of them.	Bsc

255	I wouldn't use any of these doors. Not one of them. Well, I'm picking a door which I don't like and I wouldn't use, because it's the only one.	Bsc
256	I can double it up and pretend it's the proper slide door. There must be slide doors.	Sc
257	One touch is it [inaudible 0:54:27] full. Okay, really hate these doors, but I've got no choice. Try that one. I don't even know what these look like. Probably not too awful, they're not too good either.	Bsc
258	We want that one going right down.	Sc
259	That's better. Not right, but better.	Bsc
260	Okay. Now we're going to have each doors into here, we've been … just have ordinary swinging doors,	Sc
261	as there's not very much choice. Okay, let's have … Oh no, but get the other doors in before you lose those ones.	Bsc
262	We don't want that and we've got no windows out that side. The whole we want and we got no doors, at this side has two windows, down the bottom, let's go down the bottom.	Bsc
263	This is the kitchen. We just have a window there.	Sc
264	It could be windows couldn't it? Where is the libraries? Where the hell is the libraries? Linked libraries? Now that's better	Bsc
265	Okay, we'll hold those ones and we'll have them from the ground point one. Oops, not that quite that, all right, one. Two across, right.	Sc
266	Okay. We're going to have more across there. Okay, plenty of light from the side.	Sc
267	Oh, that was meant to be rotate, not move, multiply. Multiply by one, at that over there.	Dc
268	Okay. Okay. We got to have front doors and windows, and some internal doors before we put on the roof.	Sc
269	That's a garage at the back. Right, we're going to have a front door. Hope they leave the front door.	Sc
270	We can have anything at the garage, and what small window over there. Just two thing windows along the side of the … that would be opaque	Sc
271	We've got to have opaque two doors and utilities. Utilities, don't we have originally.	Sc
272	Where do you want that utilities?	Bec
273	We just have one out there. I don't think you need because you're going to need the washing machine in the utilities room installed.	Bsc
274	Now you need a door there, you want one that's opaque. There. Whatever out wall just only wall. Window, window, not door. Door.	Sc

275	You want a double door, the utilities, but you don't want any glass in it. You don't want any glass in it. It shouldn't have glass in it. I have that a lot. That's no good. The lack of doors is problematic. The lack of doors is very problematic.	Bsc
276	Again, I'm just going to pick one which I don't particularly care for. I want it all white. I think I just did that the wrong way around.	Bsc
277	Now we want an ordinary small door from the kitchen to the backyard. Doors, doors, problematic doors. Problematic doors. A hinged door, just a ordinary hinged door, an ordinary door will do.	Sc
278	You can have the kitchen, still a huge kitchen that does now and you wanted a big kitchen cupboards that I can think there.	Bec
279	I'd have a normally, I'd have a small slide because I don't like that. I'd have a small slide for that one, but I can't find one. Because there's no libraries.	Bsc
280	Is it unsatisfactory window, but the door with this slide door and it's not particularly what anyone would want. That's better. Okay, so there.	Bsc
281	That's be too close for the wall. Come on. Why won't you let me move it? Just undo it, it's too close to the wall, but it won't bit me.	Bec
282	Oh, my God what did it do? You can stay there, I'm not working around with that forevermore. Okay, could have a door there. Now, in theory, again the doors are hopeless. How can I get one of those ones again? The slide door?	Bsc
283	Okay, the plan is not quite satisfactory.	Bsc
284	Okay, just take a roof on. Again, I'm just going to pick an ordinary roof.	Sc
285	Nine meters, why is it projecting nine meters up there instead of that? 23, six, 28. 28. 60, 69 instead of five.	Sc
286	Okay, I'm just making a railing, and oops.	Sc
287	Added columns and it's probably still too big. That will do.	Bsc
288	My goodness. I'm just going to adjust.	Sc
289	It just come up really thick. I've got my … imaging is wrong. That will do great.	Bsc

AMM Session: Participant A

NUMBER	UTTERANCE	FINAL CODE
1	I'm just letting it [inaudible 00:00:06] to start with. It shouldn't take very long. (Whispering)	Nc

2	It's a …	Nc
3	Not sure what …	Bsc
4	I'll focus on the user interaction with the space	Fs
5	and it's over all aesthetic appeal.	Ss
6	The problem design was used to provide the existing task but can moving such as walls too, can remove	Rs
7	but … ok, adding the living to the current layout does not satisfy.	Bss
8	A garage ... always this on at ground level.	Fs
9	Ok. Two bedrooms with balconies on the first floor … Two bed …	Rs
10	On the first floor the room should have reasonable space for circulation design …	Fs
11	that becomes … except for the [inaudible 00:01:33] the priority is the overall house though car, or material for further venture or structure including roofing is required	Rs
12	Finish … stone … the material …	Ss
13	The participant must … each his own … to the set of … final briefing … clearly represented … the design concept in the form of 3 models and within one hour time frame,	Rs
14	ok. Seeing off is the page … no idea about the context so … the context …	Bss
15	I assume … ok maybe I should make some context.	Bes
16	and it's … yes.	Bss
17	Ok, so I need to put stairs going up somewhere.	Bes
18	We are going to have a central stair … and going up;	Ss
19	I think the next level should house all the bedrooms…	Bes
20	so I'll … bedrooms above for more privacy.	Fs
21	ok, need a garage.	Fs
22	The garage would probably come … for the kids …	Fs
23	Depends on where the road is. …	Bss
24	The garage in west …	Ss
25	Ok, so just drawing a section of what it will look like.	Ds
26	I could … whole … bedrooms … figure out some on the back and the living, down the … downstairs.	Bss
27	doesn't matter at this point.	Bss
28	Ok, so two bedrooms …I could probably fit something a bit bigger than this …	Ss
29	… something like that.	Bss
30	That's to be quite right for the kitchen maybe …	Bes
31	Ok, slightly come back a little	Ss

32	first slight clear off the kitchen…	Bss
33	slash longer … and … for both cut the stairs to the corridor on the front divide it in half … let me push out a bit more.	Ds
34	I think I'm going to need some covered space	Bes
35	and … ok.	Bsc
36	Let's see if this works out. … Some of this …	Bec
37	Got to [inaudible 00:09:50] …	Nc
38	Alright, so now, just putting a car into the house just to see the scale of things …	Sc
39	It's pretty tight,	Bsc
40	so I'm moving all the back from over here … garage …	Sc
41	so it's roughly five …	Sc
42	no idea of where …	Bsc
43	a driveway would be coming from …	Bsc
44	Let's put the driveway on the right hand side.	Sc
45	Sort of down the left hand side …	Sc
46	so the mason … Where is it? Where is it? …	Sc
47	I can make some stairs.	Sc
48	Alright, just for once,	Bsc
49	These stairs are not … I cannot completely … I'd kill them.	Bsc
50	That's one landing … and then two, next …	Sc
51	How can I have these stairs kind of divide the space.	Bec
52	Define the living room and the dining room and keep the stuff …	Bsc
53	so threads 600^{th},	Sc
54	oh that's pretty tight,	Bsc
55	whatever… 315.	Sc
56	Yeah, that's cool.	Bsc
57	220, yup.	Sc
58	So now I'm just making some stairs …	Sc
59	get a few copies of these across and …	Dc
60	Come on … I'm not used to these commands here	Bsc
61	Ok, so there's the stairs … going over towards the kitchen … put this room.	Sc
62	Otherwise, I'm going to push back the wall … bedroom out for the carport, further back …	Bec
63	Terribly … it I could fit that way towards the ... it's so hard to … No [inaudible 00:13:17]	Bsc
64	I told you that.	Nc
65	For the meantime, I have space for a little bathroom …	Fs

66	a very chilly room in there.	Bss
67	Maybe pretty tight, let’s see … in there. Check on that one.	Bec
68	Door, garage, yeah you don’t … step over that, ok.	Bsc
69	This is for … This is on the…	Fc
70	I’ve decided … It’s going to be in here.	Bsc
71	Alright, and the … since we want the walk around the front and the back …	Bsc
72	that works well.	Bsc
73	I don’t need that wall … don’t need this one …	Bsc
74	I’ll rearrange this to be the kitchen.	Fc
75	To come out … It’s the kitchen’s side take …it’s all in the background.	Sc
76	Ok, so I’m just making the kitchen counter out of a slab … rich …	Sc
77	I’m placing the kitchen in the north east corner	Sc
78	which tend to look probably better.	Bsc
79	And having the dining room here on the [inaudible 00:15:39]	Fc
80	… Start putting some text in.	Dc
81	Now that’s work …Although I can’t put my own text.	Bsc
82	Kitchen … two …	Sc
83	And some I guess I just multiply around these stuff, but manning some of the rooms to start getting them come like spatial lay-out of it. …	Fc
84	This is kind of the [inaudible 00:16:26].	Nc
85	Obviously, these are stairs.	Fc
86	So let’s just get to the wall too to get a bit of an idea ...	Bsc
87	And trace …	Dc
88	so you know there’s something down below …	Bsc
89	Alright, put another slab down to pull the [inaudible 00:17:05]	Dc
90	So now I’ll put the slab down further back …	Dc
91	and over around here we can put the mezzanine level …	Dc
92	Too cool, yeah … ok, around here.	Bsc
93	It’s tight isn’t it?	Bsc
94	I can’t leave all that space empty … looks like a one bedroom … instead of placing a bathroom,	Bsc
95	yeah, ok, that’s not going to work so …	Bsc
96	maybe … the stairs can remain in the middle.	Bes
97	Just means, I’ll leave some space around there.	Bss
98	But the rooms are going to have to come forward … These are not going to have room …	Bss
99	I should ultimately figure out a way to share the bathroom.	Bes

100	You come upstairs, come to the landing and come back around … and you got the option of going left or right … the edge.	Fs
101	You can come that way or you coming that way.	Fs
102	maybe it should remain…	Bes
103	Or you got this bedroom that pretty much makes the most amount of sense.	Bss
104	But if it gets me phasing stuff which is fun	Bss
105	and the [inaudible 00:19:15] can be above the kitchen too.	Bes
106	The utility are stacked …	Ss
107	And this could be a pretty reasonable sized bedroom for the children.	Fs
108	What children? Probably some kind of order of business which … What's a bigger buffer for me?	Bes
109	… ok. Some nice buffer now … some … ok.	Bss
110	I'll count stairs. I'm not sure how I'm going to use that space.I [inaudible 00:20:29] I have enough of it. …	Bec
111	How's that? I think placing that … damn it … as in these walls here … and just at the moment.	Bec
112	That's a pretty tight bathroom isn't it?	Bsc
113	But it is for a kid.	Fc
114	Two floors for a young family with one child, ok.	Fc
115	You've this [inaudible 00:21:23] … or come back down.	Bsc
116	I'll make the living room a little bit bigger.	Sc
117	Keep things cool with plenty of space …	Bsc
118	Stand the books, and this becomes crossed … you can …	Sc
119	All right, there … erase all that.	Dc
120	Give it some crap.	Sc
121	So now, I'm just spatially trying to figure out what's this upstairs	Bec
122	Something like this, hopefully …	Bsc
123	let's just place a bed in there. … Yeah, give me …	Dc
124	and it's a single bed, ok.	Fc
125	Let's see if we could fit in a, a lean-in there …	Bec
126	And this is the side … both come out and you get to go to the bathroom on the side. You can't see if it's a bloody messy [inaudible 00:23:56] … We'll break down unnecessary … cool,	Bsc
127	I need two balconies. In the second floor, so …	Fc
128	The good ones are [inaudible 00:24:34] … just say it, taste. That could work... because that's lesser room.	Bsc
129	That's huge.	Bsc

130	I gather this is still on stuffing out …	Bsc
131	Takes one … still in ground level two good rounds … balconies on the first floor … bathroom … [inaudible 00:25:55] …	Sc
132	Let's type.	Dc
133	So nice to be … some kind of bathroom,	Bsc
134	at three … probably just some sort of powder room …	Bec
135	Maybe I'll make some kind of a [mudroom 00:26:43]	Bec
136	… at least I meant to do the … ok	Bsc
137	or maybe it should..	Bec
138	… through the back end, right smack … trying the stand …	Sc
139	Circulation around there, we've got circulation around here.	Fc
140	Ok, upstairs is the more difficult one …	Bsc
141	Bottom: garage, [inaudible 00:27:38] and kitchen here,	Ss
142	ok And to [inaudible 00:27:56]	Bss
143	Not sure I have … that's what I'm trying to figure upstairs …	Bec
144	that corner where … says there balcony there	Sc
145	what the … I should … these two boundaries	Bec
146	Can't [inaudible 00:29:58] … is the bathroom in there … nah …	Bec
147	if I decide to design the bathroom now … see if it can work out …	Bec
148	That is really tight …I can't …	Bsc
149	got to cut that …	Dc
150	really I might need to have a … stick around there … really …	Bec
151	the stairs … move a little … I need for it to be back here … the stairs …	Dc
152	I can … I'm just going to make the stairs now,	Sc
153	a bit bad looking …	Bsc
154	This is kind of wrong … 200th of … I hope this stays until …	Sc
155	I put that … yeah, that should do that … [inaudible 00:33:53] … Pieces…	Bec
156	What happened there?Ok, so cool.	Bsc
157	Alright, just … still working on these stairs,	Sc
158	trying to figure out what would be the best solution.	Bsc
159	Difficult to tell. I can't …	Bsc
160	when I get up to the cloud 9 Fine, at 900 … and 900 means … and 200 is 2, 4, 6, 8, …	Sc
161	and there will be four steps, so that means this is … going up 400 … and this … yup … still working on the steps. So I think now [inaudible 00:36:12]	Sc
162	Important to first single out circulation, I think.	Fc

163	I don't know … so the nearest [inaudible 00:36:34] in that space, ok? …	Bec
164	Please come back … these steps,	Dc
165	come up wrong. No … [inaudible 00:36:56]	Bsc
166	these three steps … 200 count.	Sc
167	Ok, so, almost going to stay there … so, come back down …	Dc
168	and let's make this stairwell the whole thing … come back down to 30 meters not 31 … ok	Sc
169	well … All right, so let me see that, come back the plan. Now where is this phase two? …	Dc
170	Sounds good. Let me see … not too shabby … and the landing's a little bit shabby.	Bsc
171	Just fixing the stairs	Sc
172	and they don't … it's a … that's the way we circulate up things.	Fc
173	You didn't pick more of any formal entry to the house which [Inaudible 00:39:36] … I'll give a west end … a west porch right here.	Sc
174	On the floor above, you also get, another covered area on the ground level.	Fc
175	Like so … That means that cannot go there.	Bsc
176	And so, remove that.	Dc
177	It's like some covered space here … and this guy gets a notch to the east and it's back in one and skip it all from here.	Bsc
178	All right, that's about [inaudible 00:39:49], perfect … This is all we've got.	Bsc
179	I got us through the bathroom and … well that can be a study or a something.	Bec
180	It's a bit weird, I don't know … don't know how to solve that …	Bsc
181	so I'm going to put text in…	Dc
182	This … it's so visual.	Bsc
183	I thought … just putting on some bar folds for the main bedroom that would go on out on to the living …	Fc
184	are going to their deck area. So I can [inaudible 00:43:24]. There's going to be a deck. This is going to be the deck for this guy.	Fc
185	The smaller bedroom …	Sc
186	All right, starting to look better.	Bsc
187	I need to … some windows for the corridor here.	Fc
188	This wall is kind of moved in.	Dc
189	Made up on this … it's not straight …	Sc
190	Ok, that works.	Bsc
191	This can prove … this can be a big bathroom [inside 00:44:33].	Sc

192	Say, I'm just going to put some bathroom fixtures in to get an idea of space in the bathroom.	Bec
193	I've got to use a big bathroom sink.	Sc
194	A separate shower … two ends … need some kind of basin … and basin's in …	Fc
195	sorry, that seems a bit too much.	Bsc
196	Still quite luscious …	Bsc
197	ok, so if we got [inaudible 00:45:43]… from here on … and the basin come in a slot in there's quite all right.	Bes
198	We've got a bath fix in there	Ss
199	and a shelf like probably just stuck in the back here.	Ss
200	You have your WC here.	Fs
201	It's a big bathroom …	Ss
202	Well, maybe … maybe …	Bes
203	no, I can't …	Bss
204	See if that works … Still heaps over at in that … Jesus.	Bec
205	Skip to the kid's bedroom actually, I should flip that around.	Ss
206	It would have a whole lot room …	Fs
207	The deck … how do you do that? [Inaudible 00:47:16] …	Bes
208	That could work too actually…	Bss
209	Yeah, I've cuffed, bar folds gang around there,	Ss
210	or I'll just remove that all.	Ds
211	I'm going to make this his bedroom … which is bigger and just laid better at the bathroom.	Ss
212	That's plenty of better, are there.	Bss
213	It's not much bigger though.	Bss
214	Now, I'm just trying out placing the bigger room on the east side	Sc
215	and living the bathroom on the west,	Sc
216	..giving the bedroom a bit more space …	Sc
217	and what I can do is just move the stair back around	Dc
218	so it's, the bathroom's not too big.	Bsc
219	Like that … I need to redesign this …	Bec
220	Now the stairs … That's big.	Sc
221	I'm going to put it on a bathroom counter,	Sc
222	now what? …The fuss, wish this all over …	Nc
223	and they had a shelf behind the door and back in a [inaudible 00:50:03] basin.	Fc
224	[Sneeze] Excuse me … Where is it? … Front door … [Sneeze] Excuse me. That works.	Bsc

225	Stay above from the corner … back to the corner… Shelf, also in the corner	Sc
226	but frankly a bit bigger … both.	Bsc
227	Basin’s there in your kitchen … let me see what ... There you go.	Sc
228	[Phone alert] Shut up … I think I’ve got everything in the bathroom that I made now … Yup …	Sc
229	With that change the …Ok, both … Stairs … kitchen … Ok, let’s … certainly it works for me, alright.	Bsc
230	Now, we’ll have the rest of it … push this slight back here … I need to pull this shit together.	Sc
231	Alright, I moved through back downstairs,	Sc
232	now just trying to figure out the left, if this set works.	Bec
233	I’ll have some splitting of the counters in a few … Onto the little smidgen of deck and …	Sc
234	I’m getting too much … Let’s see if … Alright, this is on the living room now, trying to get the circulation working.	Bec
235	So I’ve identified the north area as the living;	Bsc
236	the northwest area there as the living space.	Bsc
237	Bar fold sort of a pre-empt to a deck.	Sc
238	Kitchen’s at the northeast, which works well.	Bsc
239	I do want to create more of an entrance area around here	Bec
240	because it’s a bit far.	Bsc
241	This is productive from me … do I make … change that?	Bec
242	Ok … Door, happening … I guess the … Good to enter that way, into the corridor.	Sc
243	[Coughs] Maybe this counter just can’t use more…	Bec
244	I’m going to mirror it up …	Sc
245	See if I can make this a bit like that,	Bec
246	much works ok.	Bsc
247	I see it’s tight there.	Bsc
248	I can have the park in one side … can’t have … Perfect, that’s worth it.	Bsc
249	Let’s push this back,	Sc
250	so we get enough for the door out of the garage …	Fc
251	That seems to work, alright.	Bsc
252	Kitchen/ dinning … I will have … I [inaudible 00:57:44] pops out, maybe I should do the same with that. What if … what if, what if, what if …	Bec

253	What now… whatever, man … bad coffee … What's … ok … Now, I'm just in the [3D-1 00:58:38] draft and I'm trying to figure out what we're going to do on this floor.	Bec
254	That's looking a bit thin; I know … shit the whole thing.	Bsc
255	What I'm thinking, it would be interesting is at that point we start creating kind of a shift with …	Bec
256	yep … with just kind of a skylight area down the corridor.	Bsc
257	That sort of embraces that glass façade.	Sc
258	It could be around …	Nc
259	we're going to do that …here's a slight …	Sc
260	so now we've got to try and make a rift on the top of the building.	Sc
261	We're going to try out, a sort of a wing rift concept.	Sc
262	See what that looks like …	Bsc
263	I did that all wrong there …	Bsc
264	catch the [inaudible 01:00:15] and any reference of the floor in there … and here,	Dc
265	let's do the roof … yup …	Sc
266	and scan a part.	Dc
267	Well, I've to continue if, I need protection and still at least 500 [E's 01:00:58]	Sc
268	See now, I'm just suggesting the roof and the fitted windows.	Bec
269	These are the kind of things that are so much easier adjusted in the 3D window.	Sc
270	Because you can really see what's going on.	Bsc
271	Get there … so I'm going to have my … [inaudible 01:01:34] … but I'm going to drop this back a bit back down to ...	Sc
272	no …	Bsc
273	so that would … twice a 100 to put them on the floor.	Sc
274	I can't go much lower, can I?	Bec
275	Ok, then … there you are … 500 …	Sc
276	I'm just going to flip this end …	Sc
277	Start looking on the other side.	Dc
278	I'm not very keen on these materials.	Bsc
279	This one here, these are the best selection.	Bsc
280	Why don't I ever use them? … What's the correct … I'll just make it [scotters 01:02:42] … bricks look …	Sc
281	Let's scrap that	Dc
282	and set … [Sneeze] Excuse me … that's cool … [Sneeze]	Bsc

283	Excuse me … It's like a [inaudible 01:03:17] …Of course, let me make it smaller.	Sc
284	Let's make this easy for a minute …That's alright.	Bsc
285	There's not going to be much [key 01:03:57] in there	Sc
286	but I'm doing these, somewhat an exceptionally.	Bsc
287	I can … 200 back there so I need some overhang maybe like 400th or [inaudible 01:04:43] …	Sc
288	This is not correct …	Bsc
289	I am … I want this to be … first to the E …	Bec
290	and that's actually ok, because … makes this balcony better.	Bsc
291	Let's do that.	Ss
292	We'll draw the [carry 01:05:11] …	Ds
293	make that. That's one.	Ss
294	Except for the south sided bedroom, I'm just going to start placing some windows that are on the top,	Sc
295	which are only skinny but give you that southern light coming in.	Bsc
296	No, not in direct light but just,	Bsc
297	yeah, indirect light, coming in through the back	Bsc
298	so I think you quite actually open up the south … Let's open this.	Sc
299	This is going to come out fun.	Bsc
300	That didn't work …	Bsc
301	I need a … actually … why they [inaudible 01:06:37] … That's … and I'm going to put …	Sc
302	Ok … sorry … let me put this with the deck …	Sc
303	and some covered space.	Sc
304	…meters..	Sc
305	Still sold out for that little study off into the corner …	Sc
306	And this is … use the e- … I'm going to use some slide doors …	Sc
307	I'm just kind of start fitting out the rooms,	Sc
308	would look better with some sliding doors …	Bec
309	This is not actually how you do it but it will probably represent what I want at this point.	Bsc
310	Then … no … well, all of a sudden all looks … Something like so … Oops, now I … Looks more … Let's get … Let's see how the bedroom with the deck …	Bec
311	he's got the deck … far from his big ass … Just stay,	Sc
312	you've got the kitchen, dining area and the living and the garage.	Fc
313	It is tight but whatever …	Bsc

314	and the stairs which work.	Bsc
315	And now, I can design through … changes in two doors … one …	Sc
316	That's better.	Bsc
317	We make some kind of hand rail.	Sc
318	Actually I'll just make it into a wall, half closing that there so …	Sc
319	The house is [inaudible 01:11:42]. I just want to make it work … and we'll make much scale to …	Sc
320	alright that feels …	Bsc
321	That looks pretty bad …	Bsc
322	Do I want four here?	Bec
323	These would help light up the corridor, a sort of a forward raising …	Sc
324	and that's done.	Bsc
325	This is going to bring up this over-hang ... I'm doing that … doing that here as well.	Sc
326	Back down to the ground scale, the ground plan.	Dc
327	I have trouble viewing it.	Bsc
328	This could actually pop out … make up with this.	Sc
329	Standing, still I can move these guys over here ….	Dc
330	Obviously place it on the floor below.	Sc
331	Current going in … I think that needs a door …	Bec
332	that's make that, ok.	Sc
333	Let's move this front side now	Sc
334	because it is good to have a window [inaudible 01:16:08] …	Bsc
335	Bring lots of light in … ok, we'll go …	Bss
336	alright, she's suggesting this window,	Bss
337	to make it something that fits in the space.	Ss
338	The idea of this window is that it's kind of like a curtain wall sitting in front of the stairs	Bec
339	which provide you … to get some real height.	Sc
340	make….2 meters..	Sc
341	As in your light flooding in to the circulating space	Fc
342	so that it didn't feel dark.	Bsc
343	I'm just going to cut the wall off on this one	Sc
344	and … I might be full exchange in that there.	Bec
345	I [Inaudible 01:18:08] to the ceiling, raise my ending … ok.	Sc
346	Select these walls, just trim them up … walls, walls, walls… Set the walls.	Sc
347	Prepare sides. Type it.	Dc

348	That now … what about a slip? … That's fairly a very very quick idea … [laughs]. What do you think? How did I …?	Bec
349	Is this along the lines … is what … did you want more detail, like I just attempt to sort of first focus a lot more …	Bec
350	you have a roll in a space and there,	Sc
351	sort of think about how the circulation, well the rooms and how things are going to be.	Fc
352	Then I start thinking about the detail because I know, that is sort of to say that	Bec
353	I, may be focus on the overall style of the house and the color, the materials and stuff	Sc
354	but I haven't really … I haven't gotten around to that because ... [Laughs] I always work a lot more on … kind of figure out,	Bsc
355	ok, I want to figure out the spaces then I start … once I'm happy with how the space works,	Bsc
356	and like the light thing set up, then I … I'd start worrying about,	Bsc
357	"Ok, what materials going to be what".	Sc
358	I'll start thinking about what the colors are and…	Sc
359	You can spend a lot more time doing fenestration details.	Sc
360	A better way to strip windows around the top or lack ... Anything…	Sc
361	One thing I did, I just sort forgot today, was kind of put a garage door, a fully garage ... [Inaudible 01:20:38]	Sc
362	Yeah. Sort of figured,	Sc
363	"ok, there's the old house so ok,	Bsc
364	here's the garage you come in" … I mean you can sort of come in to the house this way.	Fc
365	Or you got a main entrance here if you're not driving into the house.	Bec
366	You sort of have a shared … so this would … I'd have some sort of table like you were a … where you have dinner.	Fc
367	This is the kitchen.	Fc
368	The stairs kind of split the living room and the dining room so that you have a little room	Fc
369	where you cut the stairs.	Sc
370	When you come up, you got a sort of hallway that leads the master bedroom.	Fc
371	At the back of the store, it's deck and then otherwise you could come up in the bathroom here and the other goes … and the kid has the bathroom on this side.	Fc
372	This is the fenestration that is coming off from the level.	Fc

373	Then he’s got a little deck there as well … I don’t know, I had like kind of … [inaudible 01:21:44]. Difficult without a context …Ok.	Bsc

AMM Session: Participant B

NUMBER	UTTERANCE	FINAL CODE
1	[Defense 00:01:04] of where I could incorporate some of the vertical circulation.	Fc
2	Angles would decide which should be in front and the back of the house.	Bec
3	The largest rooms are issuing is a living room ... yep, okay.	Sc
4	The plan has been provided,	Rc
5	that is correct.	Bsc
6	Okay. So to start with, I will sketch in the first floor.	Dc
7	I have to remember the first floor started a roof to my right.	Bec
8	So I'm just going to deliver that.	Sc
9	I still got a ... can start modeling the first floor.	Dc
10	Make the walls	Sc
11	think the style of windows..door	Sc
12	So my preference would be for the house to have a large open roof terrace on the first floor.	Fc
13	So I will try to put that over the living room or most of the living room.	Bec
14	Looks okay	Bsc
15	Okay, so I'm just going to make …	Ss
16	just a little bit of conceptual sketching to put over sort of roof terrace over the living room.	Ss
17	So she's sketching roughly some of the limits of where that might sit.	Ds
18	Brief also calls for how many baths or bedrooms?	Rs
19	Four rooms for …family	Ss
20	No	Bss
21	apartment is for one family with one child.	Fs
22	So I'm just going to think direction with the space and so we'll see appeal.	Bes
23	The apartment design must use the provided elevation of what [inaudible 00:03:56].	Ss
24	This apartment should include a living room, kitchen, bathroom, stairs [inaudible 00:04:17].	Fs
25	Okay. So the first thing what I would like to see is tidying up the grand floor plan.	Ds
26	.. styles and materials suit…	Ss

27	The client wanted more space in the bathroom.	Rs
28	check scale and dimension	Ss
29	So I started with having a bit of a sketching that up.	Ds
30	I lowered this a utility room adjacent to the bathroom,	Ss
31	which looks like it's not an efficient use of space.	Bss
32	Both utilities could be squeezed into the design somewhere else.	Bes
33	the dreawings look okay	Bss
34	So I'm going to use it as a starting point for reconfiguring the bathroom.	Ss
35	Now I'm just going to stick with maintaining the footprint in the building.	Ss
36	Just some sketching around the external footprint of the bathroom/utility room.	Ds
37	Just getting a feel for the building.	Bss
38	look nice of drawings	Bss
39	Okay, so I'm just sketching the bedroom as well,	Ds
40	make the grand floor bedroom.	Ss
41	Then I'm thinking that the little closet utility provide is kind of in an awkward position.	Bss
42	So he's trying a couple different options to how the bathroom could ...	Bes
43	drawing a little box at the end of the bathroom,	Ds
44	the sketching works	Bss
45	which might be a position we could relocate the closet here,	Bes
46	which would free up a lot more useful space for the bathroom.	Bss
47	If we were to place sub bath where the utility was we could ... I'm just thinking about how the building wants to work at the moment.	Bes
48	The circulation bathroom in particular.	Fs
49	Yes, it is key point for arrange..	Bss
50	The questions in which having the bath aligned where the utility room was doesn't look like it would be a great option.	Bss
51	If the toilet was located to the utility room and the bath aligned vertically along the center wall would allow us to try and lodge our closet in the corner next to the front door.	Bes
52	Avoid losing too much space ,great.	Bss
53	That would allow us to put a little more space back into the bedroom	Ss
54	and it's actually going to make the scale a little bit more efficient.	Bss
55	Okay, so I just got one quick sketch so far	Ds
56	they look nice	Bss
57	and just basically thinking about where different components in the design wants to be.	Bes

58	and make them different styles..	Ss
59	Want to get an efficient design.	Bss
60	So it's just going to start again with a little bit more refined sketch.	Ds
61	chang some structures	Ss
62	So I was going to locate the bath on the front wall of the house with the toilet sitting next to that and I need to get a [hand rinse 00:09:39] use somewhere as well.	Ss
63	and I need to get a window [hand rinse 00:09:39] use somewhere as well.	Ss
64	window locates in a right position, great	Bss
65	So I'm just going to get the [inaudible 00:09:47] and get some measurements.	Sc
66	See what we can fit into which part of the building.	Bec
67	So I'm just measuring the space we have available at the moment.	Sc
68	In term of dimension the top wall is 2200	Ds
69	and the length of the bathroom and utility room combined is 3600.	Ss
70	Just writing those down so if I have to measure them every time I wanted to know the dimensions.	Ds
71	And the of the bathroom as it stands is 1500. (Write down)	Ss
72	So after starting that, the internals separated bathroom and closet and the bedroom are not required.	Fc
73	So I'm going to move those straight away	Sc
74	and doing that sort of has just suggested that	Sc
75	a better way of arranging the space.	Bsc
76	Looking at the brief, we see a floor plan underneath it.	Rs
77	The existing walls were just making	Ss
78	So now looking at the [technology 00:11:36] at interaction,	Fs
79	I can see the circulation is probably ... it needs to be reconfigured a little bit more efficiently.	Fs
80	There is one way to consider that is we could get a sliding door is probably much more useful in the bedroom than it is in the bathroom.	Ss
81	So I think I'm going to quickly sketch that.	Ds
82	Bedroom needs to sit in here.	Fs
83	Most of the bathroom and closet I squeezed up into the house where the bedroom used to be located.	Ss
84	I would put the bath against the wall,	Ss
85	toilet next to that and needs enough space.	Fs

86	Put the hand rest in there, but then we lose part of that walking room which we want to keep and we want to keep access looking out the windows where we can.	Fs
87	So I'm just going to go to [tap 00:13:36] gets some objects so that I have more accurate understanding of what can be placed in the space that we've got.	Bsc
88	So I just started making for the bath, history of bathtubs.	Sc
89	Going to take this part of the ledge off,	Sc
90	place it into the wall.	Sc
91	The walls after, object, [inaudible 00:14:07] fit	Sc
92	Let's see how that works in terms of circulation.	Fc
93	look okay	Bsc
94	Going to put a hand rest there. So hand rest	Sc
95	... look well.	Bsc
96	I've got a toilet right here and hand rest, time for sinks.	Sc
97	Just like to place the sink basin.	Sc
98	So I'm just placing the walls into the cupboard	Sc
99	so it's going to tell me it's accurate and scout.	Bsc
100	I can move around, see how we put it together.	Bec
101	When it comes to manipulating objects in certain dimensions,	Sc
102	and scles, structures	Sc
103	I find it a lot easier to use CAD rather than sketching simply 'cause it's a lot quicker to be accurate.	Bsc
104	Trying a couple very quick configurations to see how I can maximize the efficiency of the space.	Bec
105	CAD models look good	Bsc
106	So I'm just going to go back to sketching for that.	Ss
107	Get a better understanding …	Bss
108	such as size of bathtubs and all the bathroom finisher.	Ss
109	So from that I can start to think more about how the bathroom is going to work. So yes, just try and to imagine where things will sit.	Bes
110	Try to keep in mind that we need a walking road as well.	Fs
111	One little walking room just a closet.	Ss
112	check dimensions	Ss
113	I'm thinking that this sort of area he wants to be the bedroom.	Bes
114	to relocate these doors somewhere else	Ss
115	in order to get the circulation	Fs
116	where he would of a little bit more cleanly.	Bss

117	So just doing a bit more style,	Ss
118	figure out where I want to end just using the design.	Bss
119	I'm just going to see CAD to check some dimensions.	Sc
120	I'll move the windows down, 2.2 meters wide.	Sc
121	So then it would be taking out most of the space in there,	Sc
122	it's a little bit awkward.	Bsc
123	I'm thinking I'll go back to the original concept I had which just explained the bathroom into the two-way room.	Bes
124	I keep the bedroom radius.	Ss
125	I'm just quickly, roughly making that design	Ss
126	making CAD models	Sc
127	works for a more accurate scale.	Sc
128	So bathtub in here look nice,	Bss
129	keep all that space for the bathroom is great.	Bss
130	Hand rest over here, gives you a walking room. I'm going to steal that room in there as well. Walking around [tupperware 00:20:10].	Bes
131	I'm just going to start moving the [inaudible 00:20:21 getting it to where I wanted it.	Sc
132	Just noticed that there's more discrepancy on how the side doors compared to the print out.	Bsc
133	So it moved to the other side.	Sc
134	We'll just change this slightly.	Sc
135	So I'm thinking hair basin and move the sliding door.	Sc
136	Bathtub will go over that base,	Sc
137	move the toilet next to the hair basin.	Sc
138	Just sketch some walls over here,	Dc
139	get more accurately, just getting in ...	Bsc
140	moving up ...the standing of the side ...	Sc
141	Roughing in where I want the water to be.	Sc
142	Conflicting the doors there is not really a problem.	Bsc
143	Okay. So that looks like it's going to fit in quite nicely.	Bsc
144	Copy that to..	Dc
145	I just rotated the bathroom to a different angle	Sc
146	here placing the toilet next to the bath,	Sc
147	hair basin here right next to the bathroom and do some enclosing of some of that space.	Sc
148	Just to let you know I'm on my way of getting better,	Bsc

149	a nice cool bath.	Bsc
150	but a little bit of …great	Bsc
151	so this may working well.	Bsc
152	So I was just adding the last couple of doors into the bathroom.	Sc
153	About [inaudible 00:24:51] the bedroom is actually quite a bit bigger, the bathroom is quite a bit bigger room 00:25:15].	Bsc
154	and graphically I have to say logical as well. So we've sort it out. It's liking ... better look at the [tub	Bsc
155	As I mentioned, I wanted a large roof terrace.	Ss
156	Just going to work right above the living room. We'll also need to add a second bedroom at least.	Ss
157	I'm just rereading the brief here.	Rs
158	We need interaction between the space and	Fs
159	also [inaudible 00:25:51], extension of task, doors, et cetera.	Ss
160	[Inaudible 00:26:03] Making space in the bathroom provide that publishing could ... living room, So I'm going to need two bedrooms. Brief course in [parking 00:26:28].	Ss
161	check structures, dimensions for bathroom, stairs, one that grand on that two bedroom with balconies on the first floor.	Ss
162	Once again, we can get a visual.	Ds
163	Try and reasonable space in circulation design.	Fs
164	Okay. So we'll try that the large roof terrace constitutes the balconies, two bedrooms could share those access to the roof terrace	Bes
165	and I just sketched it.	Ds
166	[Inaudible 00:27:17]. Just sketching, thinking about where each function should sit relative to other functions in terms of space with relevance.	Fs
167	Looks like you could make ... yes,	Bss
168	we put the bedrooms to the other side of the house	Ss
169	if I rush [the north 00:28:00] this up to a basically an access portal and a large terrace so it may not quite need the roof.	Bes
170	So I was thinking where the stair should sit, whether we should move the stairs from where	Bes
171	they're currently sketched in.	Ds
172	check scale and dimension	Ss
173	making stairs	Ss
174	So I'm aiming for this sheet of paper. So I need two bedrooms and both should have balconies.	Fs

175	It would be ... draw stairs in the first.	Ds
176	Keep these where they are.	Fs
177	Carry the stairs, we need some space at the top,	Bes
178	just sketching the space for the landing.	Ds
179	From that landing, the stairs could turn into ... put in there.	Ss
180	So stairs rised into two stairs at the top of the building.	Ss
181	Bedroom there, just very roughly sketching out again where different parts of the building should be, which functionally already should be in place.	Ds
182	So I think I've made it clear.	Bss
183	I'm going to keep the staircase where it is,	Fs
184	but with a turn around so it faces the other direction.	Ss
185	Sketching where I come ...	Ds
186	basically, going to come up the stairs and turn into a corridor.	Ss
187	Corridor number one are the most difficult [inaudible 00:30:57] of doing.	Bss
188	Next to that corridor, we're going to have a couple of bedrooms.	Ss
189	On the other side of the house, I cut into the roof terrace so the kids can play on.	Ss
190	Off sun roof terrace, we're going to have to place the utility room or a pulley dysfunction can get shoved in under the staircase on the other side of those wires	Bes
191	and make good use of the space, it'll be under the stairs.	Ss
192	So now I'm going to loft conceptual sketching of where things should be located in the space. the stairs correct.	Bsc
193	I'm going to insert some stairs into the CAD model	Sc
194	just so it's a little easier to make sure we put some dimensions	Bsc
195	I need to place stairs, I need to place those.	Sc
196	So I'm just figuring out which tool we should be use to model the stairs in CAD,	Sc
197	whether to use a pre-existing set of stairs or whether to create a custom stair.	Bec
198	I think a custom stair is going to be better.	Bsc
199	Basically, one of these. Turn it up. So direct the stairs of the building. need a stair that turns at the top and the bottom which is this one here. Set the default settings for now.	Sc
200	We're wearing 126 here on design. So the stairs where we get off through	Sc
201	[inaudible 00:33:31] I'm not quite what I was after. So we really	Bsc
202	I'll customize that later. Just get the head of the stairs a little bit more now.	Bsc
203	The first set of stairs we try basically no steps in that.	Bec
204	Just moving the settings to change it. We'll leave that there for now.	Sc

205	Then we can could work here around it and we come back in and fix the details for that later. Cool	Bsc
206	So the first wall, I'm just going to make some walls around where the staircase is going to sit.	Sc
207	This is the external perimeter of the house. Just copying it straight from the other one.	Dc
208	Just make that tub, basic framework I can use to identify exactly what it is that [inaudible 00:35:37].	Sc
209	Do I need these boys? And along a portal, make it a middle wide.	Sc
210	We'll also need a cargo fast [inaudible 00:36:25]. So just model one very quickly.	Sc
211	It's going to tell just how much room I've got left on the first floor for the bedroom. So it's measuring out to about 5.5 meters, which we have for regular space.	Sc
212	That will give us the internal dimension of about 2.6 meters,	Sc
213	which is a very nice size for a bedroom.	Bsc
214	The bedroom is going to be slightly larger than the other.	Bsc
215	Just very quickly modeling the two bedroom you could sit a [inaudible 00:37:55].	Sc
216	So each of these bedrooms is going to have access to a larger roof terrace.	Fc
217	I was actually going to put it into the wall to represent that terrace and the floors of the bedrooms.	Sc
218	I'll be able to make it 3D to see how it's going.	Sc
219	Check the heart of these walls. They're 2.8	Sc
220	which is probably too tall.	Bsc
221	Going to put a sloping roof on the bedrooms	Sc
222	so the side of the house is going to use 2.4.	Sc
223	great to see how the roof should sit over the room. (40:00)	Bsc
224	(40:05)Just going to go back and do a quick sketch of how the roof might work.	Ds
225	Sketching the walls of ...	Ds
226	put it into CAD.	Sc
227	Why he looks over the merit the bedrooms kind of depart what would be a roof terrace is two separate areas.	Bsc
228	Kind of use each bedroom there and private balcony,	Sc
229	which leads to a quiet space.	Bsc
230	and look very nice	Sc

231	That's the balcony also form a larger space that you just could pile their child's stuff	Sc
232	and if they have more kids. So how do we put a roof on this?	Bec
233	Just going out to the roof story, a quick experiment with our roof can sit on this building.	Sc
234	I'm going to give you the stair additive. So it gives you ... no scratch that.	Sc
235	I'm going to give you ... okay, I drew on top of the roof. That was quick. So yes, just quickly be making our roof in.	Sc
236	3D view looks great.	Bsc
237	We used the section in CAD to get a good understanding of the heights of the buildings. The heights of the different points of the space. It's much easier than trying to sketch that so it could be that I don't have to figure anything this way.	Bsc
238	Going to change the picture on the roof about 15 degrees, scaling roof. Change the height view of the first four walls. Give this stage a basic conceptual modeling.	Sc
239	It's a lot quicker to do something in 3D.	Bsc
240	It's a lot easier to see what you're doing rather than actually having to think about it and draw it.	Bsc
241	So I'm just going to model the external portion of the roof as different material	Sc
242	so it makes it a little more solid in my mind of what it's doing.	Bsc
243	No, I can't find..	Bsc
244	There's no grass materials.	Sc
245	I'd say pretty close to having a very polished outcome, great	Bsc
246	It's all just sort of a roughly drawing. But looks great and start sort of finalizing the project.	Bsc
247	Just putting in some walls that we haven't drawn.	Sc
248	I'm going to start bringing in some doors into the building using a door tool. Not quite how I wanted it the door into that bedroom. A door into the first bedroom mirrored by just working mostly in CAD in order to	Sc
249	Great that to convince myself that I'm walking around doing three dimensions as opposed two dimensions.	Bsc
250	Sliding floor doors, that's what we're looking for.	Sc
251	So I think the consensual part of the designs pretty [inaudible 00:45:31].	Bsc
252	Just modeling it in 3D to help [fiber 00:45:30] look at and essentially assist the design.	Bsc
253	Okay, I'm just going to put the full windows in. Window.	Sc

254	On this floor we don't have all ... from an [essence 00:46:31] hallway we've created.	Fc
255	And I'm going to add some posts to hold the roof up.	Sc
256	Basically, just modeling everything in 3D so that it's easy to visualize. Great	Bsc
257	So I'm just about two design contrasted columns to hold the roof up by 13 degrees part of the building. So I've just modeled the rest of the columns against to [inaudible 00:48:03] visualization to project.	Sc
258	I've got a vision in mind of what I want it to look like in 3D, I'm just trying to model that very quickly.	Bsc
259	So use [aluminum 00:48:25], different material, I guess store that profile as 'School.	Sc
260	At this point, I think it's easier to ... hold on for a sec. I think it's easier to get on stead easels in 3 dimensions would actually be modeling it as 3D items rather than sketching.	Bsc
261	Just got to add those columns we just made. Column, where is it? There it is there. So column at this end of the wall, this end of the roof,	Sc
262	sorry. Column at the other side of the roof.	Bsc
263	Next thing we'll do is get some stairs in.	Sc
264	I got 3D, great, that's basically what we wanted.	Bsc
265	I'm just editing the roof a little bit	Sc
266	so it gets over the columns a little bit more neatly.	Bsc
267	I'll go put some handrails over the top there. Object, handrails.	Sc
268	Just looking for some handrails. Great [Inaudible 00:50:16] Finishing windows, let me structure this fence and railings.	Bsc
269	I'm looking for something else to illustrate the roof.	Bec
270	You don't want the children falling off the roof.	Bsc
271	So just putting these handrails in, upload so we just [inaudible 00:51:46] look at so I can assess design qualities.	Sc
272	Make sure it's something that I'll be happy to put my name to.	Bsc
273	More handrails, more handrails, just about finish putting those in. So now we're done. So one last handrail on here.	Sc
274	[Student 00:52:45] is working toward getting it centered how it looks in 3D, great.	Bsc
275	So I'll let that settle, the computer doesn't like it. I think it may have crashed on me. That's not particularly useful.	Bsc
276	It just doesn't like to recover ..	Bss
277	I wouldn't my 3D, see if I could re-sketch out [inaudible 00:53:23].	Dc

278	Got a good idea of how I want it to work before I try and do anything in CAD.	Bsc
279	Try and section through ... it's good to go. It has too many bedrooms at the top of the house, car door on the back, the roofs hanging over the top.	Sc
280	The roof protecting part of that deck. Now I want to try and get enough lighting to the building so we have windows on the north side as much as we can. Then building the extension of the roof to this other side for protection of the storms.	Bss
281	Put a happy little child inside and see if I can [inaudible 00:55:07] to stop tracking. It's definitely not happy.	Bss
282	We'll just keep sketching then.	Ds
283	There's our fancy column and sketching headroom.	Bss
284	Let's check and make sure we haven't forgotten anything. So we've got the new design system and headroom, yep. Two floor room apartment, check. Apartment's for a young family and child, first using [inaudible 00:56:26] appeal, check. [Inaudible 00:56:31] provide extension task, [inaudible 00:56:36] bathroom, which we fixed. Now for the fluid living room, check.	Fs
285	Should have reasonable space with circulation design,	Fs
286	yes, we did that sort of. Conceptual design should have progress and have styled columns, material could move furniture of the structure to be age required. Okay, I think we submit these work on materials, but I think we are pretty close to having a good concept. So I'm going to almost as much as I would want to on this [inaudible 00:57:44].	Bss
287	I think that a tin framed roof we can't do this, holding up a shing metal roof resting on those columns that we've got out in front.	Bes
288	Just doing a quick 3D sketch of that. Sketching out a roof plan, roof design, doing that as perspective viewing.	Ss
289	look nice of models	Bss
290	I'm trying to the edge of the roof quite seen, make it look sort of delicate and so use of the immaculate materials. Just want to make sure he's [inaudible 00:59:19] present deep design concept of three walls, visiting the wire half out time [wise 00:59:26].	Bss
291	So we've got up three and [inaudible 00:59:31]. Just going to see what [Jay 00:59:36] Like the design (Laughing)	Bss

AMM Session: Participant C

NUMBER	UTTERANCE	FINAL CODE

1	On the first floor the rooms should have reasonable space. The rooms should have reasonable space for circulation designed. Fair enough.	Rs
2	Okay. Represent the design concepts, so we're talking about concept.	Rs
3	Okay, we've got an existing house, into a two-floor architectural office and it's a house at the moment.	Rs
4	Three architects, one manager. So I guess I need to work out how much space we need,	Fs
5	where I would put the second storey	Ss
6	where I would put the stairs	Ss
7	The architectural designers' interaction with the space and its overall aesthetic appeal.	Rs
8	Overall aesthetic appeal might come out of where I put that second floor and then the roof that I left over, or have to be put on.	Ss
9	The office design must use the conversion task provided with CAD Modelling, such as walls, doors can be modified, added or deleted.	Rs
10	Okay, so - just checking that this all makes sense. That is the ground floor I presume - one storey. Yeah, ground floor.	Bsc
11	Go to upper storey to the roof, fair enough. There's a second storey which is pretty blank, that's good.	Bsc
12	There's hardly any [site], there's existing walls. It looks all like solid brick. Leave that for the moment, not worry about it.	Sc
13	So, the way I design is usually with - since there's no space, I can fold that in half and that way I can trace through it once and fold down for the second floor.	Ds
14	Garage is not there so we're going to have to put that on. Need to put a garage in, there's no garage.	Ss
15	Add it, so I'm going to add a garage because that would be an external, cheap build. So I've got to add that on, there's no site.	Bss
16	CAD's useless to me right now, it's all about how I'm actually going to do it first.	Bss
17	I would assume that people are going to know the front door. The front door. seems to be the way that people would enter this place.	Bes
18	I am going to assume - I'm going to make some assumptions because I don't know about this site. I'm going to assume that that's the front door.	Bes
19	So therefore, the road is here, so therefore the road is going to come in this side.	Ss
20	That's all north, for some reason the utility is on the north.	Bss

21	Bathroom's on the east. No big deal.	Bss
22	Okay. I'm going to assume it's in the Southern Hemisphere, north being where the sun is.	Bes
23	Oh no, there's the entry. That's the logical place for the entry, okay.	Ss
24	So what I'm probably going to do is put the garage in say here, or there, if it fits.	Bes
25	I'll measure that, since I don't have a scale I need to measure that and see - narrow distance through garage, oh, that's 3600.	Sc
26	Minimum distance for a garage would have to be, absolute minimum would be five metres, so that's going to be more than that.	Ss
27	I don't want to go into the kitchen, or do I? Maybe for the purposes of this I could go into the kitchen.	Bes
28	I could come back, so that must be there then.	Bss
29	Measuring - that must be there about - yeah, well there's your garage, 2.6.	Sc
30	So if I did that, if I put the garage in there, say five metres, it would go sort of to the middle of the kitchen.	Bec
31	In which case I'd have, 1.35 left over.	Sc
32	What other utilities do I need?	Rs
33	I've got the bathroom there.	Ss
34	If that then became reception and meeting room.	Ss
35	Hallway, stairs through the middle would work.	Bss
36	Put all the designers on top. Come down to see the people.	Fs
37	So upstairs is going to be two design rooms, plus smoking.	Ss
38	Downstairs is going to be a reception, garage.	Ss
39	The meeting room might be upstairs as well, the actual meeting room.	Ss
40	Kitchen and bathroom, I could just do sort of north facing.	Ss
41	I'll just leave the utility there.	Ss
42	That looks like it's in good working order.	Bss
43	I don't need such a big kitchen, so it's going to be destroyed anyway.	Bss
44	Okay, let's put the garage in there. Brick wall through the middle - might be load bearing.	Ss
45	- yeah it's worth just leaving some of the structure intact.	Bss
46	That way drive in; come in here for reception and entry.	Fs
47	Back here for staff kitchen and storage or something and bathroom.	Fs
48	Maybe storage down there, maybe put that as storage.	Bes
49	So they could walk in, guests or people or anyone could go and use the bathroom.	Fs

50	The storage in this kitchen. There's a cupboard there, so that kind of works.	Bss
51	Something works, it's a brick wall, may as well leave that.	Ss
52	So we've got a cupboard there in the kitchen.	Ss
53	A little kitchen there, which is going to be useful.	Bss
54	measuring that it's 1750.	Sc
55	Is that good for a little galley kitchen?	Bec
56	One, seven, fifty minus 600, well there's only going to be a one-side galley kitchen. Or a little kitchen at the end.	Sc
57	Not really enough room.	Bsc
58	I might as well use the whole lot.	Bec
59	So it's actually - I'm a bit confused about this scale, but my knowledge is that 2.5 metre wide space is a perfect size kitchen,	Bsc
60	but if there's a bit of socialisation then might want -	Fs
61	so how about we put a new kitchen in. Not there.	Bes
62	So forget about the storage, we haven't been asked for it, so let's not do it.	Bss
63	Can everyone walk through the kitchen?	Fs
64	What am I doing with the rest of that?	Ns
65	That's a big car, that is a car - need a garage. Plant, sofa, coffee table.	Ss
66	Jesus, okay, running out of time.	Ns
67	I'm going to have to assume - what if I went this way? What if I went this way?	Bes
68	Five metres that way, which you need for a car. It's got to be that.	Ss
69	Okay, having trouble putting this garage in and because my understanding of a garage is it should be a minimum of five by 2.5,	Bsc
70	for a - you couldn't get away with anything less than five by 2.5 for a garage.	Bsc
71	So I need to fit that in. Trying to do it within the existing footprint.	Bec
72	It doesn't really make sense to me, but if that's what I'm being told to do then that's what I've got to do.	Bss
73	So, I would - this could still work. What am I going to do with that extra space?	Bes
74	If that becomes the kitchen, that's the bathroom, maybe go kitchen, so that's then storage.	Bes
75	I mean every architect needs storage, archives, and stuff.	Fs
76	That's where that is. Kitchen there, so garage and archives, that's fine. That's what they want.	Bss
77	There's even outdoor access for maybe maintenance or whatever.	Bes

78	If that's needed. That could be all archives, external, maybe that could be workshop or archives.	Bes
79	All sorts of things, garage, reception. That's going to be everyone's bathroom. Is that okay?	Ss
80	That's going to be the staff kitchen, with a big cupboard in it.	Ss
81	Well that's fine because you're going to need like - that's a big kitchen, you don't need a kitchen; you just need a kitchenette, just need a kitchenette.	Bss
82	But then you want somewhere to sit and eat your lunch. That's going to have to be somewhere a bit bigger than that.	Fs
83	Or do you put a door out, and go outside onto the deck out there?	Fs
84	Let's assume that that you go through and then the kitchen is actually sort of in here. So 600 must be about - so yeah, okay.	Ss
85	Let's assume it's a small little kitchenette, [unclear],	Bes
86	put a door out there.	Ss
87	So even any guests or anything walking through - I should get rid of that.	Fs
88	Well maybe it's such a small little kitchenette that even - sits like that - there's a little table there.	Bes
89	Let's put some objects in because I'm working with scale here and I've got this at my - since I've got the ArchiCAD library here I may as well use it to give myself an idea of scale.	Sc
90	This is quite a big table, but that will do.	Bsc
91	It's possible it can sit in there somewhere. Or it can go out.	Bec
92	So kitchen, storage, everything, bathroom for everyone to use.	Fc
93	Get rid of that cupboard.	Dc
94	Reception in here with sort of - it's a big reception. It's a very big reception.	Bsc
95	South facing reception. South facing reception, they can always go there to the sun.	Bsc
96	Actually, we'll do that; we'll put the kitchen on this side.	Sc
97	People can sit there.	Fc
98	Put a kitchen - actually just leave that door where it is, just turn that into an archway.	Sc
99	Bathroom, table sitting something there.	Sc
100	Massive reception, somewhere to sit.	Sc
101	That's an old living room, breaking it down.	Dc
102	Desk, how big's a desk, in that space. So I'm using ArchiCAD again to give myself a bit of scale and understanding.	Sc
103	So furniture layout, I don't think it's got a good one.	Bsc

104	Office equipment, no it's furniture I want. Tables, again desk, okay.	Bsc
105	Put that in the space. Plus there's a person sitting at it, plus there's a couch.	Sc
106	Okay, so we will use furniture layout. I'll say like a sofa layout. Let's just say it's like that sort of.	Bsc
107	So just getting an idea of size here.	Sc
108	Has to be less than that, so layout setting, I forget all this now - two armchairs, sofa with three seats, no. Two armchairs, the bottom one.	Bsc
109	Okay. So it's just a small little setting. Turn it, I think it's control-K, no. Control-E, turn it and place it in the space.	Dc
110	Okay, there's really not much space there.	Bsc
111	Might even have to lose the sofa.	Bec
112	Yeah, okay so there's not much space.	Bsc
113	It must scale a bit out.	Ss
114	Plus we need stairs up through that space because they're obviously going to go in from here.	Fs
115	So upstairs, [folding top half of paper down to start drawing second floor above] we've now got a garage downstairs; we've got that strong footprint.	Ds
116	We're leaving that bathroom, so it makes sense to leave that roof, to a degree.	Ss
117	Even come around and leave that roof, have it coming and do something like that.	Ss
118	Even leave some of that roof - I would just want to pop straight up, I guess, ideally.	Ss
119	So what we've got downstairs, we've already accommodated the reception, the kitchen, the bathroom, existing.	Ss
120	The garage, hallway - it's part of the reception, stairs will be in there somewhere.	Fs
121	Two design rooms, open smoking area and meeting room. So how big would you need for a design room and how would you get up?	Ss
122	You're getting up there through here somewhere.	Fs
123	You're landing up there,	Ns
124	the ideal is you're actually wanting - you're going to need about four metres to get to there, usually.	Ss
125	To get up a story you need about four metres.	Ss
126	Well that's nowhere near enough. So, I'll start about here somewhere and get up.	Bss

127	Yeah, it's going to have to be in the middle of that space there.	Bes
128	So will need all of that, just to do the stairs and get to the north - so that point there.	Sc
129	If you're starting here down the bottom, all the way up, in which case you'd peel off to the maybe - two design rooms and an open smoking area.	Sc
130	Smoking area, you might put to the north, up here. I'm thinking to the north. The roof over or something.	Sc
131	Design room one and design room two.	Ds
132	Would they be too small?	Bes
133	I think so.	Bss
134	Time, time ticking away	Ns
135	kay, so that there would be two and a half metres,	Ss
136	that's nowhere near enough space.	Bss
137	You need at least three or four metres for a design room.	Ss
138	I reckon three minimum - it's a bedroom.	Ss
139	ust wouldn't want anything really smaller for two people.	Bss
140	Three by three would be about that bedroom size. Which is pretty much, according to this, right past there.	Ss
141	So I could put the stairs in a different spot, slightly.	Ds
142	Reception there - what if the stairs went up, if the stairs went up on the southern wall.	Ss
143	It would be about, all the way up to there maybe. All the way up to there - three by three, three by three by three would be about that by that, so you could do it within there.	Ss
144	You could do two design rooms right along and one person could have a bit of a small one, I guess.	Fs
145	You're going to want all of that, at least. Plus meeting room, which would be another sort of long space.	Ss
146	You could do the meeting room at two and a half. You could do that there. Just do meeting room and smoking.	Ss
147	Come up here for - pretty sure you're going to need four metres for the stairs.	Ss
148	So what we've got there, and then what would you do we'd go - turn it around the corner there. Turn - the reception's under there.	Ss
149	Start about here, it's a bit of a meeting space here maybe. Go that much up, winders it's all part of that entrance. Get to look back out, maybe a window there. So we're losing that much off that. Let's say we could land there.	Bss

150	Could we do that? If we start there and go to there. So you go maybe one metre, and then another three.	Bes
151	Yeah, three and a half to there.	Ss
152	Okay, so I can get stairs in there.	Ds
153	Come up to here, the smoking area out there. Some structure that comes down, back into meeting room here - a long meeting room.	Ss
154	Which people can come up and wait	Fs
155	there and then the design rooms are - one person's there and the other one, they'll come here and they'll be over that one.	Fs
156	looking for circulation stair and that I know is the key to getting this right. Once I have solved these basic problems and know that I can fit it all in	Fs
157	So that's really what we're doing, putting a square up and all those things have to fit there. Now I need to build it, quickly.	Ss
158	Key to represent the design concept in the form of 3D models. Wow. Okay. So, let's start with the top floor because that's the thing I've got to get right. So I'm going to copy some of these walls and use them as the basis because I'm basically plopping them over the top.	Dc
159	So, ungroup, work on a maximum [unclear]. The hotkeys are different, control-shift-R, control-shift-G, ungroup. Control-shift-G, control, alt-G, control-shift-G.	Dc
160	Okay, so don't need those grouped. Control-C, go up, control-V. Okay, there they are.	Dc
161	So I don't need some of these roofs	Bsc
162	and I am pretty much going to need to get rid of them.	Dc
163	So I'm just going to assume I'm going to get rid of - actually what I'm going to do is, I'm going to open a new layer called trash.	Sc
164	Which is what I do, so it's up the top and when I don't want to see it, I don't want to see it. So I don't want to see things, so that's going to be - put the old roof in there, copy it, paste it, put it in trash.	Dc
165	Which has now left me with that roof; which now I can edit and take all the way back to there. Assuming it's going to let me even do this. I'm going to leave that bit of roof on.	Dc
166	Leave that and I'm actually going to build that back to there. I'm going to leave that essentially the way it is and I'm going to build that back to there.	Sc
167	I'm going to have to explode - explode work - explode into current perimeters only.	Dc
168	So, ungroup, I'm pretty sure that's still a 3D - still looks okay I hope.	Dc

169	No, it's gone. Okay, I'll just work around it. So, that is essentially going to keep going to there. That is essentially going to keep going to there. This is going to meet up with that.	Dc
170	That's right I can split. Ah come on, surely I can split. I can't split a roof.	Dc
171	I'm just trying to get the roof at the moment but I don't really enjoy this roof tool. I thought I could explode it and just keep it the way it was,	Bsc
172	Ah, it's giving me single-plain rooves,	Sc
173	anyway, yeah. Yeah, okay, good.	Bsc
174	Group, need to now split that, edit, reshape. Split, continue, good. So basically I'm just really roughing up, leaving the old roof as it was essentially, and trying to put the new -	Sc
175	then I'll put this new box on over the top, which is really the design concept.	Sc
176	So that and that, I need to intersect, yep and that and that, which didn’t seem to intersect properly before.	Dc
177	I need to intersect, usually I've got hotkeys for these things but in this case, I don't.	Dc
178	I haven't been able to set this up myself. So now that I've got the walls in the right place I'm just going to get rid of a few things.	Dc
179	I'll leave some windows the way they are then they'll start reading the [similar], to the above. Get rid of doors though.	Dc
180	So now, I need to put these walls in.	Sc
181	For instance to create that wall down the bottom, that wall through the middle I will be - it's going to be following that one down the bottom. So I'm going to go back to the bottom, I'm going to basically extend that wall all the way down here.	Sc
182	Then I'm going to measure it by going control-drag. It's just the way I've always done it. Back to there, 2.7, that's fine.	Sc
183	I'm going to split that wall against that one. So reshape, split it against that one.	Dc
184	Keep that part and now drag it - just see how far away it is from the bottom there.	Dc
185	I'm needing a total of five metres, so I'm going to drag it 1.3 more, because it's 3.7. So put in R-1-300 there.	Sc
186	But that's probably not even what they're wanting, but I'm going to do that because I'm going to make that the garage.	Sc
187	I'm going to put a door - a car in there just to show what I'm thinking.	Sc
188	To the elements, I'll just keep the vehicle symbols. It will be a sedan that the boss drives. Control-E, flip to north, control-mac, control-E, there it is.	Dc

189	Much too small car park, but I don't really understand that anyway. So that's got an external door, yeah we'll just get rid of that wall.	Dc
190	I'm not really sure that's a wide enough car park, 2.7. But we'll leave it for the moment.	Sc
191	That wall could always be accommodated and that could be where the nose is and probably walk around or something, I don't know. I'll make that assumption for the moment.	Bec
192	So based on that the top floor is also similar because I've now got the stairs.	Sc
193	So I can put the stairs in an L-shape.	Sc
194	I don't enjoy these stairs at all but I'll see how far I get with it.	Bsc
195	Control-E, turn it, put it in that corner, which is kind of the idea.	Dc
196	Drag, escape, drag that up to - oh no, that's where it was. Drag that back to about there. Oh, bugger. Drag that back to that. Yeah, there. Oh, bugger. Drag that, yeah, okay.	Dc
197	The width of - okay, circle, I don't know. I don't enjoy these stairs at all.	Bsc
198	Complete stairs, ah. Ah, that's more like it. I'll just use that, okay. Going to use that.	Bsc
199	I just want to make sure I can see it at the top floor. So, show on one storey up. So hopefully that shows, yep there it is. Okay, that'll do.	Dc
200	So I'm basically doing a similar wall here. Copy there and it's going to be a meeting room, I'll put it there aligned with that for the moment.	Dc
201	The other meeting room - the other design room is here, it's got to be cut short to there.	Dc
202	It's got to be at least three metres, so that's three seven to there. So put in Control-D- R 700. There's my seven by 3.3.	Sc
203	So design one and design two. You walk through one to get to the other one. I think that's fine. The boss can have one and the other people can have the other.	Fc
204	Alt-click on that because I'm just getting the same properties. Flip the side of the wall I'm working on, get to there.	Dc
205	So essentially, you get to the top here. Essentially, you have the meeting room kind of there and then alt that wall type and start here.	Sc
206	Flip the way it's working in there. So what I'm doing is creating a working space out there now. The meeting room will be 4.4 long,	Sc
207	the smoking space out the front - oh yeah, that's right. Will be at least a metre or 1.2 - meeting. So that's where that external wall needs to be really.	Sc
208	Okay, so I'm just fiddling around with walls now because I'm running out of time.	Sc

209	So I need to edit, reshape, split this wall. Because this part here needs to come back to say, there.	Dc
210	This part actually needs to join up those two pieces. [looking down at page twiceOh that's right, so actually that was going to be to there.	Dc
211	Because then you'll be able to walk out onto the smoking space.	Fc
212	An open window. Then tab, just to find the right thing. Get the wall types.	Sc
213	Okay, so they are going to walk up, so meeting room one, meeting room two. I mean design room one, design room two.	Fc
214	I'm going to have to have a slab here which is sort of representative of the balcony which I'm going to have.	Sc
215	I'll just use this way of doing it because it's quite useful. I'll put it out as far as that.	Bsc
216	That means that roof can sort of come back and hit it. Come around and hit it.	Dc
217	So there's a balcony there. There's meeting room one, meeting room, old windows, no new windows but are centrally placed, hopefully.	Dc
218	A door that I will need to mirror and flip because that just doesn't make sense. I need to flip it - flip.	Dc
219	A new slab in here because really - so I'm dragging a copy of that one. Control, just to make it into a copy. I don't know about this slab, but it's basically just that shape, minus whatever we need.	Dc
220	Use the slab tool again and just cut a hole through there to let's say there.	Dc
221	So that's - I'm assuming where that's going to go, so that internal wall needs to come to at least say, there.	Sc
222	That's just - oh, let's assume this, some sort of overhang and communication, people can have communication through. It's no big deal.	Fc
223	Need to find space for desks and things [unclear]. Very tight, very, very tight.	Bsc
224	Okay, so I need to put a roof on in the next few minutes. Let's just say that I'm going to do the same roof again.	Sc
225	So I'm going to go to ground floor, control-L, switch on the trash, okay. Chose this roof, copy, go up here. Control-L, get rid of the trash again.	Dc
226	Re-hidden trash, okay. Control-V, add to ArchiCAD, yep. That's the way.	Dc
227	There it is, but now I don't need any of that part. So that's got to be cut off there, I don't need any of that. Ah, come on.	Bsc
228	I don't need any of - hang on. So, I think this has got to be up here.	Sc
229	Okay, so some sort of square roof, that's perfect I've picked a square.	Sc
230	So let's see what the 3D looks like because basically that will show me what	Dc

231	okay so that needs to come down a storey basically, assuming everything else is equal. So X, V, yep it essentially fits on top. It essentially works into a double space.	Bsc
232	There's essentially a balcony there.	Sc
233	None of the ground floor's changed except we need to put a ground - what we need to do is - downstairs.	Bsc
234	So I guess this is what I tend to do as well, I make notes for myself on what I need to do in CAD. So I need to put a garage door there.	Sc
235	Happy with that entrance for the moment, but I possibly need to look at those windows because that'll be the front entrance and what it looks like.	Bsc
236	I need to put a backdoor there. I need to put some sort of kitchen here.	Sc
237	But that's most of the idea. Kitchen, workshop; I need to put the words in. Oh, it's 3D. 3D is the most important, okay. 3D model [unclear]	Dc
238	and I need to I think, maybe actually look okay with windows around and stuff.	Bsc
239	So basically I just need to work on the windows, doors, and things.	Sc
240	I might do that in the elevations, usually. Have I done everything?	Bsc
241	I've done the circulation design I'm pretty sure about that. I've - no furniture, oh. Only as required.	Fc
242	Well I've used a bit of furniture, but it's not required.	Rc
243	I've added and deleted.	Dc
244	Well [unclear] you can always talk about rooves and change it, but basically I've kept the aesthetic appeal, whatever it was.	Bsc
245	So east elevation, no north elevation - let's see, was I - it's saying south elevation. I don't know what they're talking about there, so we're looking at that.	Bsc
246	Yes. We're looking at [unclear], so that is not okay on the ground floor.	Bsc
247	Leave that door there. But what we need is a garage door, so the door was - okay - chose any old door to start off with, make it into a garage door.	Sc
248	I'll add a garage door, done. Make it, control-D, zooming in to get it right, control-D. I'm just going to use the same size that it's got.	Sc
249	All the same defaults, make sure it's centred.	Sc
250	So it's 200 there, so just press R-100, that's how I measure and drag at the same time.	Sc
251	Control-D and then just make decisions on the fly.	Dc
252	There's a door there, all that was existing, that's fine. Just rip the kitchen out and leave what you want. That's what they get.	Bsc

253	That desk there is going to be now a desk and chair, hopefully. Can we do desk and chair?	Sc
254	Show desk, okay. I often do copy, drag and drop just to get a new object and then actually change what that object is.	Dc
255	So now I've done that, now I'll just put a chair in.	Sc
256	I just want to make sure, I guess, that these things actually work.	Bsc
257	Then mirror that and just put it that side and assume that the receptionist is going to sit, say, there.	Bec
258	There's not much room. Actually, she's going to sit under the stairs.	Bsc
259	So drag the whole lot that way, mirror it across that axis and drag it now back into that space.	Dc
260	With enough space, say drag 600, to squeeze past and sit under there.	Dc
261	So she's going to sit under the stairs. I assume that works.	Bec
262	These guys are going to be not whole furniture layout anymore, but chairs of some sort.	Sc
263	To save, design, un-chairs, like that. Drag that over there, E, flip it up north, and drag it up there. So there's going to be one there, one there, turn that.	Dc
264	Use the drag instead of turning and copying at the same time by pressing control.	Dc
265	I think it's a really bad hall.	Bsc
266	How wide is that? Flight width one.	Sc
267	Yeah, I can make it one, two - flight width I'm going to make one, one.	Sc
268	Yeah, that's just going to make it a bit better, hopefully. I'm not really happy with that reception area,	Bsc
269	but you know, so be it. I've only got a few minutes.	Nc
270	Stairs up past that window and then in there.	Sc
271	Leaving all that they way I accept I'm turning that into a door, so pull that door across.	Sc
272	Just control-drag, pull it into where the old one was.	Dc
273	Take window, delete. I'm going to have to flip it because it's now an outside door.	Dc
274	I won't bother changing the actual object. But that's that.	Bsc
275	So entry, kitchen, bathroom. Probably delete these.	Dc
276	I'm sure if it came to it we could start to talk about what they exactly want it to be and how you'd manage the kitchen, kitchenette, and stuff.	Fc
277	Going to change that into just a kitchen cabinet for the moment. Kitchen cabinets, maybe a three one.	Sc

278	Okay. Drag it into place there just to prove that we've got enough space basically. Actually I might just [unclear] the floor one.	Dc
279	Okay, so I'll drag [unclear], so there's just that and that and that. That's the kitchen, heaps of space for - oh, that's the chair. That's all the same upstairs. Need a balustrade.	Sc
280	So downstairs I did the door, I didn't change the windows. I did that door. So I'm just checking everything that I've done now.	Bsc
281	Now, what I actually really need though is a nice set of double doors out here.	Bsc
282	So that's probably going to be not a window, but a door.	Bec
283	So I'll just put a door in again, same as I did before.	Sc
284	Chose it again, might even do control-z, control-alt-z, to delete it and then basically have it selected.	Dc
285	Switch to open doors. Doors, doors, sliding doors are nice - flat top sliding doors. Not pocket. Nice glazed ones probably.	Bsc
286	So sidelights - that's not right, have I got the right ones?	Bsc
287	Okay. Yep, some nice sliding doors out,	Bsc
288	get rid of that window because it's useless.	Bsc
289	Just put it right over to the edge	Sc
290	because that's what everyone loves.	Bsc
291	Actually, I'll get rid of - keep that window and just put that over here.	Dc
292	Get that at the top of the stairs.	Sc
293	You come up to a window there;	Sc
294	this guy's got a window here.	Fc
295	It's all north, north, north, everyone's happy.	Bsc
296	Down to the south here, there's maybe two windows,	Sc
297	let's just make it better than that.	Bsc
298	Maybe here there's two windows as well. Just sort of pairing them up.	Bec
299	So [unclear] dragging and then pressing control and then just putting another one in.	Dc
300	I don't really want any east - so I'm just going to do southern light, but you do want it in two directions.	Bss
301	So, I'm centring that, literally just find the wall position and centre.	Sc
302	It didn't work. I think I just need to do a balustrade and it's probably done.	Bsc
303	So, objects, I'm pretty sure there are balustrades here somewhere.	Sc
304	Building structures probably, fences and railings, something architectural that they'll like. Check it out in 3D, that's the sort of thing architects will like. Rail, twisted rail on straight, something like that.	Bsc

305	Okay. Just whack it in there and see what happens.	Sc
306	Zoom in, this is where I again need to have something	Dc
307	I just restart, so control-E and control again gives me the copy function.	Dc
308	Drag one that way, so again just quickly press control and it drags it for me.	Dc
309	That there has got to be -	Bec
310	I'll put it just inside there because we'll probably be doing that. Actually, that slab might be rather, just coming around proud.	Bsc
311	In which case that's going to sneak in there. Just put that back to there and that one's going to be sitting there.	Sc
312	So I should probably put all these things on the edge. It's going to be sitting there and it's coming out too.	Sc
313	Oh, that might be proud as well. Let's just do that, with a clash of elements there but it kind of doesn't matter for these purposes.	Bsc
314	Because one will in the end override the other. I will actually though, just move that now.	Dc
315	So there is a clash but now we've actually made a decision.	Bsc
316	That wall there is not there though, it needs to come back and marry with that.	Dc
317	So now, I might have a smoking area - that has to be a door.	Bec
318	No, it can be a window - you just come out through the meeting - you only smoke out there if there's - yeah, no, that's fine. Generic perspective.	Bsc
319	I'm just looking at it. Ah, I've got a north-facing balcony, which everyone should be happy with. You've got downstairs looking all pretty much the same.	Bsc
320	That slab doesn't look right. I've got one minute probably to fix that up.	Bsc
321	I've got a garage door coming in. I've got a front door which I should fix up but I don't have time to.	Sc
322	Existing roof downstairs, got existing stuff going on, with utility going out there. Oh yeah, yeah, whatever. I've got something going on the top here. So I will now just check out - oh, that's the slab, so the slab should be okay.	Bsc
323	That slab - actually no, it's these walls.	Bsc
324	These walls need to - hang on what's the thickness of the slab?	Sc
325	Or is that the ground, downstairs walls? I just want that to look right.	Bsc
326	These walls here start at 3100. Okay, so these walls here need to go up to 3100,	Sc
327	oops. I'd rather them go up, so check the east elevation, and north elevation.	Bsc
328	That's kind of okay - why do we have that roof there? I don't want that roof there.	Bsc

329	That's 3100	Sc
330	ah. Oh, bugger. Okay, that's annoying. I hate these rooves,	Nc
331	so that's going to have to go up to 3100. These are going to 3100.	Sc
332	Okay let's see if I can make that [unclear]; I'm going to trim elements to roof shell.	Dc
333	I'm going to keep that bit. Yeah, okay. That's a bit of a muck up, but anyway. I don't know what's happening there. Oh, [unclear], okay whatever.	Bsc
334	South elevation, that wall there has to go up to 3100.	Bsc
335	I get some of them right, not all of them right. West elevation, that wall there also to 3100.	Bsc
336	Okay so now when I look at the 3D I'm probably going to be a bit more happy.	Bsc
337	Go back to my turning thing, yeah. Oh, terrible entry, all flat façade, but that's the way it is.	Bsc
338	Yeah, the slab comes out. Yeah okay, it doesn't look so bad.	Bsc
339	I'll go down to 2800 again.	Sc
340	I feel like that needs something. There's that roof back. The slab kind of needs to come out and do something interesting I reckon. Ah, that's the south elevation I'm worried about. That's funny, that sort of needs to do something interesting there.	Bsc
341	Okay, so what I was just basically mucking around with then, because it's the final minutes, and I just want it to look okay, is that that side, that front, just looked funny being all-plain.	Bsc
342	I think you'd have some sort of rain cover for these things. Actually, you know what you'd have is even some sort of cover out here too.	Bec
343	So I'm going to put that out here and just have some nominal cover.	Sc
344	So maybe 2400, 2400 out that way. Oh, that's a bit far - 1200, then put back out 600, so 1800 out.	Sc
345	I'd even do the same to here maybe. I don't know it just feels like it needs something. Oh, I've lost something. Yeah, something like that. I don't know, that's what I would end up doing probably, is doing something that gave you a sense of entry there, something new and interesting. I could even do the side one up.	Bec
346	So I'm just doing it at the moment, making it out of the slab but in actual fact, it would probably be something different.	Bec
347	So maybe line that up for no other reason and another 600 out. So just using what the stud-tool's good for, which is the sort of push and pull.	Sc
348	So 1800 that side, 600 all around there	Sc

349	it sort of might give it some new, modern entry feel. The entrance is down underneath there.	Bsc

AMM Session: Participant D

NUMBER	UTTERANCE	FINAL CODE
1	Okay so from what I can gather from the brief it's two sales people, with one of them being a manager	Rc
2	So just having a quick look at the plan, 3D CAD model, actually presently it doesn't actually look anything like a gallery.	Bsc
3	Like it says in the brief, it's an existing house.	Rs
4	Presently there's one, two, three, four, five rooms - utility, sleeping, bathroom, kitchen and living - and I think more needs to be made or the actual space needs to be utilised differently and better	Bss
5	there's north I think will be quite important.	Bsc
6	Obviously an art gallery cannot have direct sunlight due to the actual art being held in the actual gallery space.	Bsc
7	But that doesn't mean it can't have soft light and indirect light.	Bsc
8	So that will depend on the north and also depends which side of the art gallery I can possibly open	Bsc
9	or have expansive glass or even have some decking as perhaps part of the kitchen, possibly reception too, balcony if it could work in there,	Sc
10	with a big balcony on the first floor	Sc
11	Okay so I'd be doing I guess most of the designing on paper. I'll only be going onto CAD when I've possibly nearly finished the actual design because I feel it's impossible to design on a screen.	Bss
12	So I will be drawing and most of the design will occur on the actual sheet itself.	Ds
13	It's a bit weird having to actually talk about what I'm actually thinking but I guess what I normally do is actually look at the plan, look at the elevations, especially if it's existing, and then I try and visualise what can actually happen, visualise spaces, visualise entrance, visualise where the walls should go, and that usually takes quite a bit of time.	Bss
14	Okay so I'm currently just having a look at the model and having a look at the elevations and it appears to be just a conventional Australian house or a bungalow as we'd call it,	Bsc
15	Okay so as I'm looking at the plan I'd probably just try and do a massing kind of drawing.	Ds
16	A massing drawing for me means just identifying what the gallery needs	Fs

17	and then placing it on the plan	Ss
18	and trying to decide where the best areas for those areas should be.	Bss
19	So I'm just going to write on the brief what it actually needs.	Ds
20	So one, the gallery should - so it needs a reception. Two, showroom or the art gallery room. Three, kitchen. Four, bathroom. Five, storage, storage room.	Fs
21	It says hallway. I'm tending to not - I'm probably tending to disagree with a hallway but we'll see.	Bss
22	Hallway and then stairs to get onto the - stairs to get onto obviously the first floor.	Ss
23	Two working rooms - I presume they're possibly admin or one for each of the people, the manager and the sales person.	Fs
24	So just before I do the massing I guess what I normally tend to do then as I get the brief is to have identified what the client	Rs
25	I guess the client needs or has asked for.	Fs
26	Before I actually start designing I analyse what the client has asked for	Fs
27	and what those rooms should represent through analysis.	Bes
28	So I'll take the gallery room for now. So the first question is what it's for. Well it's to show artwork.	Fs
29	Well in this instance it's probably if it's not sculptures its walls or even partitions.	Bes
30	The gallery room will be the largest of the rooms I guess.	Bes
31	So scale, it says in the brief that it should be - it says a big showroom.	Ss
32	But I guess the scale will depend on the size of the existing house and it will also depend on trying to organise the other facilities.	Bss
33	But the actual showroom is the most important aspect in the gallery	Bss
34	But the show and art workroom will be the most prominent aspect and should be the most prominent aspect of the design.	Bss
35	So we've got walls, partitions to hang the artwork up.	Ss
36	Like I've said, there should be no direct sunlight.	Bss
37	But that doesn't mean that there can't be some soft light or some indirect sunlight coming through and filtering through	Bes
38	and that can be done by possibly high level windows or some skylights.	Ss
39	But I do think it's important to have a mixture of both artificial and sunlight or indirect sunlight in a showroom.	Bss
40	Materials. Materials, and I guess also colours, neutral.	Ss
41	Walls should be white or perhaps just off-white.	Ss
42	Flooring. I guess the flooring can be discussed and it could be anything really.	Bes
43	It could be timber flooring, tiled.	Ss

44	not carpet; carpet wears out and if there's a lot of people going to be walking round I guess that over time it would wear out quite quickly.	Bss
45	So possibly timber or tiles;	Ss
46	it's easy to clean and take care of too.	Bss
47	I'm aware of the time restrictions on this so just to I guess move along.	Ns
48	So I'll move on.	Ns
49	Reception. Reception needs to be at the front obviously	Ss
50	so it's as the person walks in it's the first thing they see	Fs
51	and they're quite comfortable walking up to the actual reception.	Bss
52	So it should be at the front and visible,	Ss
53	preferably I guess [0:20:00.2] before entering the actual gallery itself and that's for security purposes too.	Fs
54	Again I'd probably spend a lot more time analysing what reception was.	Ns
55	Just moving on.	Ns
56	Storage room. Storage room would be directly linked to the art gallery.	Ss
57	So as I'm actually talking now I'm actually writing all this stuff down so it's a bit of a matrix.	Ds
58	So the storage room should be directly linked to the gallery.	Bes
59	The reason I say this is usually - or I'd say the reason that the storage room, and I presume the storage room is to store the artwork that's not being used or the future art shows or something like that,	Fs
60	it needs to be directly linked because both areas need to be temperature controlled	Bes
61	and need to be of the same environment, the same I guess environment in terms of temperatures and air temperatures	Bss
62	and opening one door to the actual storage shouldn't have any effect on the actual artwork itself.	Bss
63	So that should be somehow directly linked through some doors into the actual storage room off the art gallery itself.	Ss
64	Stairs. That will all depend. Location will depend on I guess the design.	Ss
65	If it's staircase to only the offices and only staff can use it	Fs
66	then it doesn't need to be part of the art gallery,	Bss
67	it doesn't really need to be part of any interaction with the public and that possibly too will have a good impact on security.	Fs
68	Bathroom and kitchen. Bathroom or toilets for the public should be either - I would say they need to be quite close to the gallery	Bes
69	but I would possibly put them at the reception.	Ss

70	The reason I'm saying this for now is I guess because it's going to be such a small art gallery the last thing you need is possibly people in and out of the art gallery into a toilet.	Fs
71	That goes for possibly the smells and possibly people just really in and out quite regularly.	Bss
72	So I'd possibly put it in this instance near the reception.	Ss
73	Scale of the bathroom.	Ss
74	That all depends on how many people are using the toilets and if the staff are going to use it too.	Fs
75	But for this instance I'll just - I'll guess that it's just one unisex toilet for the staff and for the public too.	Fs
76	Kitchen. I will assume that the kitchen is for the staff	Fs
77	and if it is for the staff I would tend to put it up on the first floor with the offices.	Ss
78	The kitchen could be part of the balcony	Ss
79	and could actually open out from the kitchen into the balcony which would be quite nice depending on the orientation and the sun.	Bss
80	So I would in this instance assume that the kitchen is for the staff and I would be putting it on the first floor with the actual offices or next to the offices	Bes
81	So I'm just writing down these notes now.	Ds
82	Okay and then lastly offices. As they're on the first floor they should be situated where they have the best sunlight filtering through	Bss
83	and as I don't know the location of this house so I don't know what the views are like,	Bss
84	I don't know if there are any views or if there's anything obstructing the sunlight,	Bss
85	if there are any high rises or two-storey houses nearby that are actually having an effect on the sun.	Bss
86	But I would assume that the two offices on the first floor should have a really good	Bes
87	should be a good place to work with some daylight coming through	Bss
88	with some open expansive windows,	Ss
89	possibly even a small balcony, I'm not too sure.	Bes
90	Materials - again I'm kind of rushing through these - materials for the offices.	Ss
91	Again you could use the same flooring throughout for continuity or possibly when you get to the offices they could be carpeted	Ss
92	or they could - just going back to the showroom and art gallery, it could be just polished concrete there	Ss
93	which would be quite nice.	Bss

94	So the polished concrete would be just in the gallery room	Ss
95	and as you enter anywhere else then they could actually transform then into some timber flooring so actually I guess a bit like a threshold of moving into another space	Bss
96	and the gallery space is actually quite special and that's where the polished concrete is.	Ss
97	So I've gone through them quite quickly and it gives me these eight points I guess.	Bss
98	It gives me a quick indication, possibly just analysing from the last 10 minutes, of what I actually need to do.	Bss
99	I didn't realise I'd talked so long then.	Ns
100	So now I'll just get onto the massing. I'll keep to the same - just out of ease I'll keep to the same layout.	Bss
101	So I'm just - sorry it's hard to actually talk and think at the same time	Ns
102	I'm just outlining the actual walls of the house and they're just the external walls only on the premises that there's no structural walls inside and they're not load-bearing and everything is picked up on the external walls.	Ss
103	I'm really assuming there.	Bes
104	Then I can actually open the whole thing out to begin with. [0:30:00.2]. So what I've decided to do is out of ease I've decided to swap the plan over	Bss
105	so now the living room or the existing living room is at the top	Ss
106	and that makes it easier because that room seems to be quite expansive	Bss
107	or quite a rectangular space	Ss
108	which is perfect for the art gallery.	Bss
109	This little I guess utility	Bes
110	sorry no	Bss
111	At the minute I'm just thinking quite quickly of where these different things can actually go.	Bss
112	I've put the gallery up top where the living room is	Ss
113	and I've changed the plan orientation.	Ss
114	Then to the side I've put the storage which is directly linked to the gallery room then.	Ss
115	I think what I'll do then is I'll probably leave	Bes
116	I'd leave that central wall in as a partition for the gallery	Ss
117	and that acts as quite a nice partition;	Bss
118	there's two doors on either side and one could be the entrance and one could be the exit.	Ss

119	So as you enter there could be some kind of path all the way through the gallery and you come out.	Fs
120	So I'd probably keep them or I'd at least refurbish	Bes
121	I'd manipulate them to depending on what they were.	Bss
122	Gallery too. The partitions in the gallery I'd manipulate depending on what kind of	Bss
123	and then I guess following the analysis there needs to be a reception	Bes
124	so that would possibly - for me it's quite - there needs to be some kind of congregation area outside	Fs
125	and that could be a general platform with stairs leading up to it.	Ss
126	So firstly I'm getting rid of the roof	Dc
127	the pitched roof.	Sc
128	So I'm manipulating the gallery at the minute. So I'm getting rid of one of the windows	Dc
129	and I'm just expanding the other one	Sc
130	or making it slender so possibly even 300 in height	Sc
131	but I'm actually making the width	Bsc
132	the width is - I'm just going to try two metres for now	Sc
133	and then the actual height is possibly 300	Sc
134	no it's five metres.	Bsc
135	So I'm just positioning the window in the middle	Sc
136	and then I'm going to actually lift the window.	Sc
137	So again this is all to do with bringing direct sunlight in, some kind of sunlight.	Bsc
138	So that's going to be off the ground.	Sc
139	The doors for the gallery, there's no need for doors and that just takes up all the space.	Bsc
140	So I'm going to take those two doors out. So I'm going to take the doors out at either side	Sc
141	so there's a high level window to bring in some sunlight.	Bsc
142	If I was to do this properly I'd have to do some proper analysis with the sun angles	Bsc
143	so it doesn't reach the actual art that's on the walls.	Sc
144	So I'm just going to quickly get rid of that central wall between the sleeping area and the kitchen area.	Dc
145	So there's - I guess there is a partition there now.	Bec
146	Even to be honest there doesn't necessarily need to be a door.	Bsc
147	So I'm just going to bring the door in;	Sc

148	they don't need to be doors.	Bsc
149	So just making possibly a metre width either side.	Sc
150	So they act as - so it's a bit more of a partition and the entrance, in and out.	Sc
151	Then I'm just going up to the reception. I'm getting rid of that door to the side	Dc
152	- sorry window. I'm going to swap it for the door	Sc
153	So at the minute I've created a door and I'm creating this kind of platform outside.	Sc
154	The reason I'm doing that is to actually approach a gallery as it is now and just to expect to just open the door and then you're straight in there is I don't think - there should be some kind of approach to the building.	Bsc
155	I know this is totally impractical	Bsc
156	but I'd probably lift the building so it was on stilts so there was the possibility of some stairs leading up to this kind of platform.	Sc
157	What that does to it actually approach that you know that's a front entrance and then take it - go up the stairs.	Fc
158	So I'm trying to visualise things.	Dc
159	So the thicknesses of - this platform should be quite thin.	Sc
160	It shouldn't have really any weight to the actual building.	Bsc
161	So at the minute they're average tread and average head but the thickness I've given is 50mm	Sc
162	it could even be smaller than that depending on what it's been made out of.	Bsc
163	Okay so there's an approach to the building now. I'm actually also going to put some - because there's some stairs leading up now that it needs to be on stilts.	Bsc
164	So I'm just having a look in the objects, if I can find them.	Dc
165	Okay, I'll just put some slabs there.	Sc
166	So these will not be my chosen columns and I don't know what the width -	Bsc
167	the size of the columns will depend on the size of the house I guess.	Sc
168	So at the minute I'm just creating these columns. [0:45:01.6]. Okay so I'm just placing these columns where I think they go.	Sc
169	So I've got 15 minutes left.	Nc
170	So I'm just trying to decide where to actually put the other stuff. I guess I can put the staircase up against that partition wall	Sc
171	There's no - the objects haven't been provided so I can't get to the actual - I can't get to the staircases themselves.	Bsc
172	So I'm just going to have to quickly do slabs. So I'm just creating these slabs now.	Sc

173	The staircase I guess would be open, possibly even cantilevering off the partition if we could make it structural.	Bec
174	The reason I'm saying that is because there's not much space. It would be better if it was all open.	Bsc
175	So I'm just trying to get my head around where to put the reception	Bes
176	So in the left-hand corner near the - well it's there already - the kitchen - sorry the bath, the toilet room. I'll keep that as it is for now.	Bss
177	I know I said I'd do that storage. So I'm just manipulating that left-hand side now where the existing toilet and utility is.	Sc
178	There's a little cubby-hole or I'm not sure what it is, it looks like storage.	Bsc
179	I'm getting rid of that.	Dc
180	So that's opened that out and then for some reason that wall is not in line with the actual - the bathroom wall, the right-hand side of the bathroom wall is not in line with the actual external wall.	Bsc
181	So I'm just going to move that wall across so it's in line with the external wall	Dc
182	and then hopefully I've got enough room	Bec
183	then to put a door in which would act as storage.	Sc
184	I'm just manipulating some of the windows to open the outside.	Sc
185	The window - what I'm trying to happen - what I'm trying to create is a window that's the same size as the opening into the actual gallery itself	Sc
186	so when people actually walk past they can almost see directly into the gallery.	Fc
187	So there's no point having just a generic sized window.	Bsc
188	So I'm just measuring the size of the opening to the gallery I've created which is about 850	Sc
189	and then I'm just going to make that window 850.	Sc
190	Then I'm just going to place it in line.	Dc
191	I'm going to make it longer too.	Sc
192	So the whole point of this window is to engage with people in the street; they can see directly - almost as they walk past they can see into the gallery space	Fc
193	I'm just going into the toilet area now, the toilet. Either there needs to be obscured glass or it needs to be smaller	Bec
194	so I'm going to make it smaller.	Sc
195	So I'm just working on the stairs again because I need to get the stairs all the way to the first floor.	Sc
196	These walls are quite high at 2.8	Sc
197	so the staircase actually looks - it's going to have to be longer.	Dc

198	So I'm just - I'm going through - I'm jumping from one thing to another here which isn't good.	Bsc
199	I'm just manipulating this side now with the windows, the front windows,	Sc
200	so again people can look in.	Fc
201	I'm going to make the window - I'm going to lift the window so it's in line with that slender window I created earlier to see into the gallery.	Sc
202	Okay so now I've created that ground floor.	Sc
203	It's very rushed.	Bsc
204	I've lifted the whole house on stilts to create this kind of almost like a floating -	Bsc
205	it's not a balcony but a congregating area before leading into the actual gallery itself.	Sc
206	So there's a few steps getting up to this platform and then you can enter the gallery.	Fc
207	So right in front of you as you walk into the gallery you'll have your reception somewhere near the -	Fc
208	if you have a look at that drawing somewhere near the staircase.	Dc
209	I've got my staircase which is a very long staircase - I'd have to revisit that - which runs along the actual partition.	Sc
210	Then as you walk through the front door too you'll see reception	Fc
211	you can visit reception then a couple of paces back and then you can enter the actual gallery itself.	Fc
212	The gallery, there's plenty of wall space all four sides.	Sc
213	As you enter you can - although it's not a large space you enter one side and you come out through the other.	Fc
214	As you come out through the other the toilet is on your left and then right in front of you -	Fc
215	you can clearly ….	Nc
216	So that's basically the ground floor. I'm not happy with it but it's the start of a design anyway.	Bsc
217	Then just quickly on the first floor. As you go up the stairs, in fact the stairs would be better orientated the other way because as you go up the stairs it's quite narrow once you reach the top;	Bsc
218	you'd have to kind of a U-turn.	Sc
219	Anyway I haven't got time to think about that.	Nc
220	So I'm just creating a slab.	Sc
221	In fact you could have some kind of - sorry again I'm thinking the design through in my head as I'm looking at the drawing or the CAD.	Dc

222	I'm wondering if we can have a double-height space where the staircase is.	Bec
223	So you go up the staircase and there's no roof really; there's just a double-height space so you can -	Sc
224	that would mean you could put your artwork or permanent artwork possibly or some kind of artwork in that reception area on a higher level.	Fc
225	I'm going to put the slab on top of the offices on top of the art gallery.	Sc
226	The floor to the offices might need to be acoustically at least considered.	Fc
227	The reason I'm saying this is you don't want people walking or having the noise transferring down to the art gallery itself.	Bsc
228	So I'm just putting a - I'm not too sure about the thickness of the slab, 300 possibly, probably be less than that.	Sc
229	I'm going to create a sliver, possibly about 500.	Sc
230	I'm going to make that some kind of glass on the first floor so you can look down.	Sc
231	I'm just changing the - it has glass paving. It doesn't have glass. So I changed that to - how can I not have glass?	Sc
232	So I'm just replating the ground floor now	Sc
233	sorry the first floor.	Bsc
234	What I'm thinking is that the offices don't really need to be conventional offices.	Bsc
235	So I'm thinking - so that first floor now can overlook the actual reception area.	Bec
236	So the offices are above	Sc
237	I'm just drawing a section. So I'm just quickly drawing a section; it just gives me an idea of what I'm trying to do.	Ds
238	I'm trying to manipulate these stairs to give me access to the light.	Bss
239	So I've drawn some sections	Ds
240	and the reason I've drawn some sections for the design process is just so I can understand what I'm trying to create.	Bss
241	Jeff wants me to finish it so I'm just going to quickly	Nc
242	so I'm putting the balcony as part of the offices at the back.	Sc
243	So I'm just going to have to create an overhang for the balcony.	Sc
244	So I'd have to - I don't know what the thickness of the balcony is	Bsc
245	so I've created a 300	Sc
246	So I'm just increasing these walls now because I've created this double-height space.	Sc
247	So over the toilet and storage area it doesn't need to be double height	Bec
248	so I can just place a single story up above there. So I'm just putting that in now.	Sc

249	That could be - for my instance it's going to be a flat roof.	Sc
250	Again that's 300 I guess	Sc
251	I'm not too sure.	Bsc
252	I'm just going to drop it so there's a bit of an up-stand.	Sc
253	Also I haven't used any - I don't know if this is worth noting that I haven't used any walls in terms of [unclear] CAD tools;	Bsc
254	they've all been slabs and I've just manipulated the size of the slabs to what I want it to be.	Sc
255	So I don't know if that's worth mentioning or not.	Bsc
256	So I'm just putting some walls	Sc
257	sorry some windows.	Bsc
258	So I've just drawn quickly the first floor	Ds
259	and then I'm just going to quickly draw a partition wall.	Ds
260	I'm actually - again I'm going to use - there doesn't need to be any separation really	Bsc
261	so it's just going to be a glass divide.	Sc
262	This is two offices now. Perhaps the manager, I don't know, depending on what he does - perhaps the manager needs a bigger office so I've just made his a bit bigger.	Bsc
263	So you come up the stairs, you turn right and there's areas.	Fc
264	So I'm just creating a balcony for the first floor.	Sc
265	So I've just drawn the balcony.	Ds
266	Now I'm just drawing the top of the staircase.	Ds
267	So as you go up the stairs now you turn right and there's two offices and there's a balcony that can look over the reception and staircase area, two balconies -	Fc
268	sorry two offices and the two offices have a balcony that they can actually go onto.	Bsc
269	So I'm just going to finish off the balcony.	Sc
270	So I'm just putting some balustrades in again and I've put the wall in. I'll put the wall in	Sc
271	So it's really hard to actually talk while I'm trying to at least design.	Nc
272	So I'm just putting the wall, back wall in for the offices.	Sc
273	Then I'm putting two doors in, one for each of the offices.	Sc
274	Do you want me to finish?	Nc
275	I'm having difficulties because - what CAD is this - I'm having difficulties putting some of the doors in.	Bsc

276	I'm not used to this CAD. I'm just getting mixed up with the two walls and I can't identify which wall it is.	Bsc
277	So I'm just going to see if this works.	Bsc
278	So I've just pulled one wall to the side to see if it'll - because I'm just going to have to	Sc
279	I can't put the doors in for some reason so I'm going to create just openings [1:25:00.4] instead of the doors.	Sc
280	Then I'll just place that wall back. Hopefully there'll be some - at least a couple of - yeah. Okay that's a door.	Sc
281	Okay so two doors for the balcony, offices overlooking -	Sc
282	okay that's worked out quite nicely.	Bsc
283	Then I'm just going to put the roof on now.	Sc
284	So I'm just following the outline of the slab for the roof	Dc
285	and then I'm just lifting it into place on top of the roof.	Sc
286	I'm going to give it another 300 depth and then I'm going to	Sc
287	I've changed the materials to the roof to timber for now.	Sc
288	I've just noticed that the partition wall for the offices is sticking out so I'm just going to decrease that.	Dc
289	So I think that looks quite nice now.	Bsc
290	The only thing I've got to put is the front first floor window in which would be at the front of the house.	Sc
291	So I'm just putting that in.	Dc
292	So what I've done is I've just copied over the partition and rotated it	Dc
293	and then I'm just manipulating it to the size of the actual window itself	Sc
294	so it will just need to be a bit bigger.	Bec
295	So I'm just increasing it again.	Sc
296	Okay so I think that's done.	Bsc
297	I don't know how I've ended up bit looks like some sort of Corbusier modernist house or modernist art gallery in this instance with a flat roof	Bsc
298	and I think it works quite well.	Bsc
299	If I had more time it would definitely more windows and it would need a window in the offices.	Bec
300	If I've got time now I might do just	Nc
301	- just lifting the - trying to place the window in the office.	Sc
302	I found it extremely hard on this CAD because my settings aren't tailored towards me. On my computer my CAD settings are tailored towards my preferences.	Bsc

303	I'm going to leave it but there should be another window there.	Bec
304	I've just noticed that the roof doesn't quite go over the edge of the building so I just need to manipulate that.	Bsc
305	That's better. Okay that looks pretty good to me.	Bsc
306	Jeff? Are you happy with that?	Nc

AMM Session: Participant E

NUMBER	UTTERANCE	FINAL CODE
1	Okay, yeah. I'll just talk every time I think.	Ns
2	All right. Now I'm going to get the major elements of the brief that I need to add.	Rs
3	So I'll just be circling them.	Ds
4	The major examples, female owner wants more space for the bathroom. More space in bathroom, living room. Stairs on ground floor.	Rs
5	Two bedrooms and balconies. Tile materials a priority. Okey-doke.	Rs
6	I'll be sketching them…	Ds
7	All right, now I'm looking at the [Tad 00:02:22] model.	Dc
8	sketching ground floor	Dc
9	considering… interaction	Fc
10	we can possibly make if…	Bec
11	Labeling; okay,	Dc
12	so I just want to make sure I know where the entry is.	Bsc
13	So we're going to put a line in for the entry.	Dc
14	Okay. Going to select the entire roof	Dc
15	and move it to the top.	Dc
16	let's try 300..	Sc
17	No	Bsc
18	450	Sc
19	ok, it works	Bsc
20	Going back to 3D. Using Explorer. No, we're not going to use Explorer. Let's orbit around.	Dc
21	Okay, so we're going to add a – what do we need?	Bec
22	The stairs.	Sc
23	which shape may fit..	Bec
24	Okay, so we're going to add a L-shape stair.	Sc
25	It's going to be just off the entry.	Bec
26	So we put the L-shape stairs just off the entry.	Sc

27	We’re going to make this a void above.	Sc
28	Adjusting the stairs,	Dc
29	hight .. weight..	Sc
30	then we move to there	Sc
31	Okay, so I’ve got the stair around.	Sc
32	Check it in 3D.	Dc
33	Okay, it’s not bad.	Bsc
34	Now we’ve got to add the second – first story slab.	Sc
35	So we want that to basically cover the entire first floor, except the void space.	Bec
36	All right, so that’s created a good landing there.	Sc
37	Make sure I put my little walls.	Sc
38	Extend these walls	Sc
39	Check it in 3D.	Dc
40	Go over here, just going to adjust the stairs. All right.	Dc
41	Let’s do a bit of – I’m going to do perspective and	Dc
42	I’m going to walk through models for circulation.	Fc
43	Checking layout again	Rc
44	So, maybe we’ll change the stair.	Bec
45	Okay, we’re going to change the stair because it’s not going to fit properly.	Bsc
46	Okay, so we’ll do a straight stair;	Sc
47	reposition it.	Dc
48	Rotate cad models…	Dc
49	Yeah, that’s all good.	Bsc
50	Return to … Now all to do is put that in there.	Dc
51	Second floor, I’ll make this terraced balcony.	Sc
52	Okay so that’s going to be broad space over there.	Bsc
53	Just exploring again in 3D	Dc
54	checking the levels. Okay, it’s looking good.	Bsc
55	Now, three and four … So we’re doing two.	Sc
56	Let me get rid of this utility room.	Dc
57	Now [inaudible 00:09:13] this wall. Okay, need to go right here,	Sc
58	delete this one, delete that one	Dc
59	move the walls..	Dc
60	2.5 meters..	Dc
61	Some of this, we’ll maybe use some interior walls.	Sc

62	I'm going to maybe put the bath up here, through this doorway, closer to here so we'll offset that.	Sc
63	look 3d views..	Dc
64	Going to flip that around as well, like that.	Dc
65	Okay, so it's a bit better.	Bsc
66	Put the bath into there.	Sc
67	Make the kitchen a bit bigger as well.	Ss
68	make the window ..	Ss
69	Just analyzing the brief again. Two bedrooms with balconies on the first floor.	Rc
70	First floor; upstairs gets out. There's the balconies and below here, we need a stair, kitchen, living room.	Sc
71	So we're going to get rid of this whole interior wall.	Dc
72	Shorten this wall so that we've got a bit of a break.	Sc
73	Walk through..	Fc
74	[Inaudible 00:12:25] keeping it at the time being.	Sc
75	Make this the kitchen and then we can do the bathroom.	Sc
76	Okay, we'll just step back a bit. Do undo.	Dc
77	Now I'm just going to change the downstairs living room.	Bec
78	Going to reduce that size to the door.	Sc
79	Try this one..	Bec
80	Give this a bit of break there and move this back towards … start it there.	Dc
81	3.5…	Sc
82	Now we have the bathroom and … Copy, paste.	Dc
83	I think I don't want to do that. And these …	Bsc
84	All right, so you want a big bathroom, big lounge room, and [inaudible 00:14:18] kitchen behind there	Rc
85	Try to switch where the kitchen is.	Bec
86	I'm going to … Turn it about fifty yards.	Sc
87	Make it bigger..	Sc
88	Go into a window. I'm just going to change this set to [inaudible 00:15:37] this section point.	Sc
89	Okay, so that's better.	Bsc
90	All right, now pretty happy with – oh, no,	Bsc
91	So we'll offset that for the bathrooms.	Sc
92	So we've got a kitchen, bathroom, bigger lounge room.	Sc
93	Maybe I'll make these a bit longer.	Bec
94	So we're going to move to the top floor now.	Sc

95	So clear out … I’m just going to move our roof	Sc
96	so if we want to put it back, we can put it later.	Bec
97	check layout again..	Rc
98	Right now we’re going to put the two bedrooms with balconies on the top.	Sc
99	Start by … We’re just going to put an internal wall – external wall, sorry.	Sc
100	An external wall basically around the top floor.	Sc
101	Make that continuous so we can put the whole wall around the top here.	Sc
102	Basically that same shape.	Sc
103	look great	Bsc
104	I want these walls to come all the way down [inaudible 00:18:56].	Sc
105	Bring that down	Bsc
106	so it’s going to look a little better	Bsc
107	we’ll make it.	Sc
108	Add 300 to it.	Sc
109	Add three, one, zero, zero	Scc
110	Check it in 3D.	Dc
111	That’s more like it.	Bsc
112	All right, now … I have an interior wall. So, roughly, just going to get a [person 00:20:38] out to scale.	Nc
113	All right. Just going to get a figure so I can use it to scale so I can [inaudible 00:21:00] we use this guy.	Sc
114	Okay so maybe we want to make that [inaudible 00:21:09] area a little bit bigger.	Bec
115	Just going to extend that sort of 500 [inaudible 00:21:16].	Sc
116	Let's try 600..	Bec
117	Let’s fix that out, adjust my stairs.	Sc
118	Ok, so I need to put stairs going up somewhere.	Bec
119	I’m going to switch on reference layer. [Inaudible 00:21:45] as line above the current story.	Sc
120	so I can trace..	Dc
121	Adjust the height of my stairs. So we’re going to bring that back to that, there we go.	Sc
122	[Inaudible 00:22:36] so we can see 3D. All right, and …	Dc
123	nice..	Bs
124	Putting interior wall in.	Sc
125	I want to access the [inaudible 00:23:46], so measure that	Sc
126	450	Sc

127	Just going to make this a little more relative to … So, [inaudible 00:24:02], plus my stairs.	Sc
128	So we'll make that just a bit bigger.	Sc
129	That's better.	Bsc
130	All right, now we're just going to repeat that sort of voided space over here so we've got more of a [inaudible 00:24:46] thing happening here.	Dc
131	[Inaudible 00:24:57]. Here we go. X minus 1400.	Sc
132	I'm going to make this leave.	Dc
133	All right, I'm going to extend that out there.	Dc
134	1200	Sc
135	Just putting it in groups again.	Dc
136	I'm just going to readjust the walls at the top	Dc
137	so we can put our bedrooms in.	Sc
138	Looking back at the briefs again just to make sure I've …	Rc
139	Living room, kitchen, bathroom downstairs. Two bedrooms with bathrooms on the first floor.	Ss
140	Okay. So now we're going to do that.	Ss
141	Make it the same size.	Ss
142	1200	Sc
143	and the same material	Sc
144	Okay so, what I might do is [inaudible 00:27:34]. I'm just exploring the 3D to see if I'm [inaudible 00:28:02].	Dc
145	So I'll make a master bedroom and a smaller bedroom.	Ss
146	All right. Going to put a door in in the dining room,	Sc
147	put that between there, sort of a – Join the bedroom.	Sc
148	Make sure we have enough space for a bedroom there. [Inaudible 00:29:31].	Bsc
149	Readjust these again.	Dc
150	1300	Sc
151	[Inaudible 00:30:07] X plus 15 … 15, 10.	Ss
152	All right, so that looks a little bit better.	Bsc
153	Now we need the balcony like so.	Bec
154	Moving that walls to here..	Sc
155	What we could do is make this an entire room.	Bec
156	This is going to be a shared courtyard down here.	Bec
157	Okay, now we're going to just start a small bedroom and a large master bedroom with a shared courtyard	Sc
158	so now it's looking pretty good.	Bsc

159	See how it looks in 3D.	Dc
160	The bedroom's sticking out of that.	Sc
161	That's not bad	Bsc
162	And then through here, the boards face up. [Inaudible 00:32:42]	Sc
163	not bad.	Bsc
164	One large bedroom. [Skirt 00:33:05] them completely. Okay, so they have a bedroom here.	Sc
165	Probably need some internal access. Might want to make it there	Fc
166	then color it all the way through.	Sc
167	adding a window on …wall	Sc
168	Now we've got a balcony there, we'll put some doors in that.	Sc
169	Double doors,	Sc
170	nice French doors opening up that.	Bsc
171	look 3d views..	Dc
172	Or maybe even put some sliders in.	Bec
173	We'll do some sliding doors. ,	Bsc
174	What have we got? Yep, sliding doors over here	Sc
175	undo that,	Dc
176	I'm going to make the corner. Okay, so	Sc
177	we've got sliding doors. [inaudible 00:34:44].	Sc
178	[Inaudible 00:34:57] Walk through straight	Fc
179	long window. It's the window fixed frame.	Sc
180	Rotate cad models…	Dc
181	Looks good.	Bsc
182	So I'm just going to pick the – we'll put it in the middle.	Sc
183	All right so the sliders [inaudible 00:35:42] into there,	Sc
184	600	Sc
185	may need to make it –	Bec
186	make a wall around here	Sc
187	but we'll make it half the size	Sc
188	make the window ..	Sc
189	so we've got a nice balcony.	Bsc
190	So we'll make that … No, I can't do that. Cancel that [inaudible 00:36:21]	Dc
191	and we'll make it front meter of the stage. Just going to take our guy and put him in there.	Sc
192	I'm going to make that corner, put a funky second one down there.	Sc
193	What have we got? 1500, okay, [inaudible 00:37:37].	Sc

194	no,	Bsc
195	maybe more…	Bec
196	1600	Sc
197	If it's ceiling height. That'll do at that stage.	Bec
198	Do the same thing.	Sc
199	That one, not bad.	Bsc
200	Let's put a door in, oh – Let's put a door in here.	Sc
201	I'll just give this a bit of materiality.	Sc
202	Just going to make a roof that give the –	Sc
203	I'm pretty happy with the rest of it	Bsc
204	so I'm going to give it a bit of material and color.	Sc
205	So we're going to give outside a … What have we got? How do I [inaudible 00:39:29] some noise?	Nc
206	Seeing stone paving. [Inaudible 00:39:44] just there. Stick that back through.	Sc
207	All right, so now I've got – might make that hatch so we can see it in plain.	Sc
208	Recover [inaudible 00:40:25], make it [inaudible 00:40:31]. We'll go in some. Pavement, cool looking pavement. Yeah. We'll do that, we'll do …	Bsc
209	We mark just to make hatch	Sc
210	, we've got this 24 by 24, yeah cool. All right.	Sc
211	Let's move this down a bit.	Dc
212	Okay, it's looking good.	Bsc
213	I might just put a little [inaudible 00:41:59] as well. Just going to put a [inaudible 00:42:06] in here and say "void."	Sc
214	We'll send it out. There it is,	Bsc
215	look at that.	Dc
216	Now you put a line through it just so you make sure we know it. Take that thing, make sure it's okay.	Sc
217	Cool.	Bsc
218	All right now, just to put the roof.	Sc
219	We'll try it with the original roof and see what we can do.	Bec
220	Okay, so the original roof looks like …	Bsc
221	So I'm just going to cut that. You want to [inaudible 00:43:09] the roof on your grid.	Dc
222	That's about right. So I'm going to cut him and put him up there.	Dc
223	Hm, no. So we're going to give the roof a bit more … We won't use that at [inaudible 00:44:13], we'll just use a different style.	Sc
224	It's looking pretty funky at the moment.	Bsc

225	It's sort of [inaudible 00:44:26] on the one side and [inaudible 00:44:30] on the other. Just looking through the roof [inaudible 00:44:39].	Dc
226	Where's the roof at? So I'm just going to set up that roof line	Bsc
227	and I'm going to draw our roof.	Dc
228	and extend that wall a bit..	Sc
229	See what it looks like in – yeah, it's pretty cool.	Bsc
230	Going to take down the pitch.	Sc
231	Put it at [inaudible 00:45:40]. Yeah, like that. Do a bit of an – the extensions that we want taken out 500 [inaudible 00:46:09].	Sc
232	Put that at 600,	Sc
233	500. Do the same thing.	Sc
234	All right, so now we're just going to put a roof over in our other bedroom.	Sc
235	Match up these.	Dc
236	These going on 600 as well.	Sc
237	Push it out maybe halfway out like that.	Sc
238	Get a bit of indoor/outdoor happening. Put a [inaudible 00:47:42] on these pictures a bit.	Sc
239	Put that 2080,	Sc
240	about 320. Save to 20%.	Sc
241	Let's bring these walls up. [Inaudible 00:48:13].	Sc
242	So we can mirror that in now as well.	Dc
243	Making it as corrugated line so it's changing the material. Changing the material to a corrugated iron, if I can find it.	Sc
244	Nope. Okay, we're just going to make it an iron roof. Iron roof with this glass through;	Sc
245	clear glass [inaudible 00:50:10] to the middle.	Sc
246	We'll make all the steel walls on the top floor.	Sc
247	We want a nice siding,	Bec
248	so we're going to do a medium wood siding.	Sc
249	Cool.	Bsc
250	Let's finish adding some side over there as well, so we're going to go medium siding.	Sc
251	That side should fix up the [slab 00:51:18].	Bec
252	Bring that slab back here then save again. [Inaudible 00:51:35].	Sc
253	Change. Bring these walls up and	Sc
254	cut them to the roof.	Sc
255	Then line crop to roof, crop tops. Adjust the rooftops.	Sc

256	Okay, I know nothing new, but … Crop the roof again, see if it looks [inaudible 00:53:15].	Bec
257	Yep, perfect. [Inaudible 00:53:31].	Bsc
258	Now just a few quick … Now I'm just going to put a bit of – a few more windows in.	Sc
259	Just adjust the size a bit [inaudible 00:54:20] and I'll be fine.	Dc
260	So this references the [inaudible 00:54:28].	Nc
261	And that will go around the side. Okay, we're going to multiply these, the [inaudible 00:55:37] this one	Sc
262	Make these big windows,	Sc
263	I believe we were at three 700.	Sc
264	What we'll do is we'll multiply them again, so we're going to make them multiplied by one	Bec
265	all right. Let's see, that's cool, sort of window side. It's looking pretty weird, but cool.	Bsc
266	Maybe sliding windows [inaudible 00:56:55]. Multiply, so two, don't really like to drag.	Bsc
267	We'll do that by distribution. We'll put those like that.	Sc
268	Okay. This is good. [Inaudible 00:57:29].	Bsc
269	Okay, so it looks like I'm clear. I'm just doing this so we can cut the roof. I think I'm done. I'm good. All right.	Bsc
270	Nearly done, hold on. Nearly done. Okay, so, there we have it. Oops. That is finished.	Bsc
271	All right, so just checking a few final things. Just going to drop that down, put it down there , some more right there.	Sc
272	Cut that right in the doorways.	Dc
273	Just adjusting the final windows. Match them up internally.	Dc
274	I wouldn't worry about it.	Bsc
275	Match up the stairs. That'll count. Finish the [inaudible 01:01:44] so you get the same height.	Sc
276	o we'll change that to ten and one. All right. Change the mix and call the adjustments here for final, with a [inaudible 01:03:09].	Sc
277	checking design requirements..	Rc
278	All right, so done, done, done. Signing in to see if it's. Okie doke.	Bsc

AMM Session: Participant F

NUMBER	UTTERANCE	FINAL CODE
1	The first thing I'm going to do is read the brief. The design brief is for the 2-floor architectural office design, so I'm just going to read that first.	Rs
2	Okay, so what I'm going to do, I'm just going to write down, in bullet form, what the requirements are, so.	Ds
3	The office should include the reception area, a meeting room, kitchen, bathroom, stairs.	Rs
4	Two design rooms, and I've just drawn them as a box,	Ds
5	and I've just labeled it Design Room 1,	Ds
6	and I've labeled that one Design Room 2, and opened this connecting area, on the 1st floor.	Ds
7	The first … wall [inaudible 00:01:30].	Ns
8	Okay, so I'm going to draw a line and above that line,	Ds
9	I'm going to do my two boxes because that's my Design Room 1 and that's Design Room 2 with a smoking room,	Ss
10	and all of these, I'll draw a little line to the ground floor.	Ds
11	So, I've just drawn to the ground floor, so we have the reception, meeting, kitchen, bathroom and the stairs. Upstairs, design room, and Design Room 2 and a smoking room. Okay.	Ds
12	Okay. All right. Now I'm just looking at the existing plan, seeing where everything is.	Ds
13	This is going back to the paper, sticking it over, over the original template, and I'm just marking out the existing plan.	Ds
14	Drawing over, drawing down the walls, stone walls, so we have bedroom there.	Ds
15	Looking at the template, I have kitchen here, can be a living room there, bathroom there and utility there.	Bes
16	Putting the template to one side … what is required on the ground floor?	Rs
17	So, on the ground floor we need reception, meeting room, kitchen, bathroom, stairs.	Rs
18	So, I'm looking at the list that I drew earlier and I'm also looking at the sketch that I've just drawn on the piece of paper.	Ds
19	That's not my list.	Bss
20	Looking at my sketch, looking at my list, at my sketch. Looking at my list, looking at my sketch.	Ds
21	Thinking about the layout of what's existing in the bathroom, where it is.	Bes
22	That can stay where it is actually.	Bss

23	So, I took the bathroom off of my left, look for the location of the bathroom, the utility room …	Ss
24	just draw over the lines.	Ds
25	I think that can stay where it this.	Bss
26	The stairs can lead off of the reception.	Bes
27	So, we can have one box there,	Ss
28	this will be the reception plus the stairs	Bss
29	so it will be a circle in that box,	Bss
30	just behind the stairs and the reception go together	Ss
31	This deals with that one and that deals with that one.	Bss
32	Kitchen and meeting room. We can have a living room, can that be meeting room?	Bes
33	Kitchen can stay where it is straight into the meeting room,	Bss
34	service for bathroom … still sketching out all I've got.	Ds
35	Let me think. Reception: we can convert the bedroom into the reception	Bss
36	and we can have the stairs there.	Ss
37	So, that wall will go.	Ss
38	I'm scribbling out that wall, the kitchen, the meeting room, the bathroom.	Ds
39	The bathroom there which is now the reception into the [inaudible 00:06:47].	Bss
40	Okay. Or, I'm forgetting the door.	Bss
41	There we go. Reception, stairs, meeting room, bathroom off of the meeting room.	Ss
42	Again, I'm sketching roughly.	Ds
43	Okay. Now, I've got to put a cabinet in. Just wondering to myself to put a cabinet on the wall.	Ss
44	Looking at my sketch to see where I drew the lines,	Ds
45	and I'm going to where I find the roof.	Sc
46	I show in … okay. Now, I'm going to take that door out	Sc
47	and highlight..	Nc
48	Pick my own load. I'll just get that wall together, get rid of that wall. Three. This wall.	Dc
49	Going to the plan. Selecting the 1st story, making the lines, going back to hide the roof.	Sc
50	Okay. That's wrong.	Bsc
51	That wall. Okay they were going to extend that wall all the way down.	Sc
52	Clicking that wall … we have to hide the roof.	Dc
53	Now I just have the wall. With the roof outlined,	Sc
54	Bring that wall across and I'm going to insert the door, and put that there.	Sc
55	That's the wrong door.	Bsc

56	So we have the door settings, and bring up what type of door. Just have a normal door. Okay.	Sc
57	All right. So, I'm just going back to my original sketch just to make sure I have done what I originally sketched.	Bsc
58	Okay. Now, I'm going to put my stairs in.	Sc
59	I have to find the stair tool. Where is the stair tool? I can't find the stair tool. The stair tool is over there.	Nc
60	Okay, what type of stairs? Because this room is split, , we've got to review my sketch.	Bec
61	Back to the sketch, just want to see the stairs that were originally right.	Ds
62	So, just marking that as ST1.	Ss
63	Okay, I'm ready to go to the CAD program and choose a spiral staircase	Sc
64	because it's a small room.	Bsc
65	Okay. I'll just stick it in there.	Dc
66	Move my spiral staircase around.	Sc
67	I'm just going to the 3D view now to see if that's appropriate.	Dc
68	That's in there; have a look. I guess not too bad.	Bsc
69	Now, I'm just measuring the distance from the top wall to the bottom wall is 6, 6400	Sc
70	and moving the main wall back a little bit	Sc
71	in order to give us some reception area space.	Bsc
72	Now, I'll move that door down here.	Sc
73	Okay. Now, I'll put in another wall just there	Sc
74	and that gives us enough reception space.	Bsc
75	Put that in there.	Sc
76	Now we can have a seam … move that wall across	Sc
77	and now I'm looking at doors for the meeting room.	Dc
78	The meeting room doors will go there. Okay.	Sc
79	We've still got the kitchen, still looking at the CAD model. I'm looking at the plan	Dc
80	I put my stairs in, freed up some room for the reception, had the main meeting room toward it straight off and I'm saying what I'll do,	Bec
81	I'll get rid of that. Don't want that	Dc
82	and that gives plenty of space for a meeting room there.	Sc
83	Okay, next we've got the 3D model. I'm looking at that.	Dc
84	Okay. We've got the meeting room and kitchen, the reception room.	Sc
85	I'll tell you what, I'm going to make my staircase up into the kitchen	Sc
86	because I realize that there's not much room left.	Bsc

87	What I'll do is we'll get rid of that, move that back to there	Dc
88	and I'll move that door over—	Sc
89	no, no, no, no, no. Step back.	Bsc
90	Move that sort of 3D model to see the position of the door on the stairs.	Dc
91	Tires are inappropriate.	Bsc
92	I want to move that window on the 3D model.	Sc
93	I'll delete that	Dc
94	and Shift, Shift-Auto across, [inaudible 00:15:09], so go back to the plan.	Dc
95	Put in the door, move the door over to the left.	Sc
96	Essentially create a small kitchenette area.	Sc
97	Okay, make sure the sketch … just marking on the sketch here.	Ds
98	Put this on drawing in the kitchen unit, sink, cupboards.	Ds
99	Looking back at the 3D model while updating my plan.	Dc
100	Marking up my main doors just so I'll remember.	Sc
101	Stairs here, so you can enter here.	Fs
102	Just sketching routes that people would take.	Ds
103	Drawing in solid line where the kitchenette wall is,	Ds
104	o that If... I would be sketching that …	Ds
105	making that stronger. Looking back at the plan. Okay.	Bss
106	Okay I'm making that line, looking at the plan. Looking at the sketch, drawing in that line.	Ds
107	Sketching in where my double doors go. Just … sketching over that.	Ds
108	Just rubbing out the lines here.	Ds
109	So, the bathroom goes … meeting room.	Ss
110	Looking back at my plan, yeah, okay.	Bss
111	This is my reception area. I'm just marking that up.	Ss
112	My entrance. Walk in, and have the reception …	Fs
113	if somebody's polite enough they can go make coffee, or go straight to the meeting room, or go upstairs which is about ...	Fs
114	Okay. Now, I'm just looking at the 1st floor.	Ds
115	How I'll let my ground floor up.	Ss
116	Looking at my sketch getting out a bit of paper.	Ds
117	Laying it over what I've done originally, mark out the ground line, mark out the door.	Ss
118	Looking at that line, just going around the whole thing that I did previously.	Ds
119	At my toilet, the stairs, door, kitchenette area. The line coming all the way down like that now.	Ss

120	So, I've redrawn my original sketch and planning on the 1st floor.	Ds
121	Now, I'll go over that with the lines that I think are going to make up,	Ss
122	going back to my brief. The two design rooms and the smoking room. Okay, the stairs are up here.	Rs
123	The main wall and the main wall. Essentially, you could have quite a big space directly out of the supporting walls, isn't that part of that?	Bes
124	The beam across, into the sketch.	Ds
125	Okay, going back to the CAD model to put in some walls.	Sc
126	Looking at my sketch just to make sure that I'm standing in the right place above the kitchenette	Dc
127	and I'm drawing in my walls.	Dc
128	So, one just goes straight like that, two, three … just a great, big, square.	Sc
129	Now, I'm just tidying up the lines, joining them together	Sc
130	Okay, now I want to go and see what that looks like in 3D. Okay.	Dc
131	Now, I'm going to go to delete there…	Dc
132	I can't remember how to cut the roof out. How do I do that? I'm just trying to work out how to get rid of some of the roof.	Dc
133	I can't remember how to do that. I'm just making a 3D model	Sc
134	and to try and work out how to get rid of the roof. How does that work?	Dc
135	Two and a hundred.	Sc
136	How do you do that again? I can't remember how you do that. I'm stuck on just trimming the roof at the moment.	Dc
137	Just do any way. Do this. I wonder? [Inaudible 00:23:09]. Darn it. I can't get up on it right now…	Nc
138	Okay. I'm putting those two walls together, the stairs go there. Okay, back to, back to the 3D control.	Sc
139	Move the roof like that.	Sc
140	Okay, and try to remember how you cut the roof off, which I can't remember. Okay. Dear. Now, what actually … I can't remember to do it one way, so I'll do it another way. What I'll do, is I will put a donking right smack in the middle.	Sc
141	See where it turns up. Control down.	Sc
142	Turn that show off.	Dc
143	If I slant, at the top, six of these.	Sc
144	At the bottom, two of these [inaudible 00:26:28] turn this back on, okay.	Sc
145	Solid [inaudible 00:26:44] issues. [inaudible 00:26:45].	Nc
146	I can turn layers on, commit new, this remains hidden.	Dc
147	Okay. I doubt one, but again. Snap on layer settings. This remains hidden	Dc

148	okay, I think I made it. Cheating while I'm doing it.	Bsc
149	Now, okay back to the plan. Thinking again.	Dc
150	Move my slab. Go along. Going up and just drawing my slab.	Dc
151	Now, I F5 and there you go. Snap, okay. Now, all I need to do is click that, and that.	Dc
152	Point there and just extend this out to there and that should be enough for that.	Sc
153	Okay. I'm going back to my original notes that I made on my list just to make sure Design Room 1, Designed Room 2. Okay.	Bsc
154	Going back to the CAD drawing. This is me nuts, spinning it around and zooming back in.	Dc
155	Okay. Get a feel for it.	Bsc
156	Okay, so you come up the stairs, there you go.	Fc
157	If I was there, and I walked forward. It's just a small walk there	Bec
158	so we line this place up a tiny touch. Small, yeah. Small over there.	Sc
159	Bring that back in touch … wall to wall. Bring that back over there.	Sc
160	Wall down, okay so the windows … not only… Okay. One, two … and there.	Sc
161	Try to figure out which is the west side?	Sc
162	Okay. So, plenty at east, plenty at north, plenty at south.	Sc
163	So, let's count two, three, one.	Sc
164	Okay. Now, let's get the side on, selecting that. These move down to a respectable spot.	Sc
165	Definitely bringing them up. Okay. Definitely widen them.	Sc
166	Nice.	Bsc
167	Big windows north and south.	Sc
168	Put another one right there. Go back to the three, again. Just reaching up, across.	Sc
169	Okay, so that's that. Seems to be 19.	Bec
170	Seventeen, 19.	Sc
171	That's not fitting in.	Bsc
172	Okay. I was into the wall. I could have put a bit more there, too.	Sc
173	Get as much light as we can possibly get.	Bec
174	Now let's do that to the window. Let's push that out, nice and big.	Sc
175	Plenty of light. Excellent.	Bsc
176	The door there. Make it so like in.	Sc
177	Move the path in and out but I just don't … move it here. Okay.	Sc
178	Would give it a little bit more there.	Sc
179	String that. Strike that. Go back to 3D.	Dc
180	Select those two walls	Dc

181	Move that one. Select that wall, move it down; select that wall, move it down	Sc
182	I'll get over it, fine, I guess. Let's finish it off.	Bsc
183	So, yep. Yep. Yep. Okay. How does that look? Okay, I'm just checking out the final 3D model.	Dc
184	I don't like that.	Bsc
185	Balustrade, balustrade. Now what does he want? Just change the material of the balustrade to grasp something.	Sc
186	Make it look a bit better.	Bsc
187	Make glass clear	Sc
188	make glass blue or what?	Bec
189	Glass blue,	Sc
190	okay.	Bsc
191	Okay. A window right there. Now, I'm just trying to select the window so I can move it.	Sc
192	Okay. Now, I will click on the node, stretch it, single out a little bit.	Dc
193	Floor level looks a bit weird.	Bsc
194	So, what I'll do is get to the roof layer,	Sc
195	and I'm playing with the slab.	Sc
196	So, I'll move that back, and go to the 3D view to see what that looks like.	Dc
197	Now, we're going to go to the window, for the smoking room, down to the floor	Fc
198	make sure it's accessible through there.	Bss
199	checking brief. I think we'll just leave it at that for now. Okay, I think I've finished this one, Jeff.	Bss
200	Okay. All finished?	Ns
201	Yeah.	Ns

AMM Session: Participant G

NUMBER	UTTERANCE	FINAL CODE
1	Okay. So now, I'm reading the design brief for the art gallery. Two sales people.	Rs
2	Okay, so, yeah. Focus on customers' interaction with the space, okay. Overall aesthetic appeal.	Rs
3	Ground level and two [working] rooms. Big balcony. First level. Gallery does not need a garage, but it may be used for another function.	Rs
4	So there is a garage, no. What? Confusing.	Bss
5	Does not need a garage, but it may be used for another function.	Bes

6	Rooms should have reasonable space, circulation, [unclear] and conception designs, that's priority [unclear].	Rs
7	Colour, material, furniture, structure, okay. Which design takes [unclear] satisfy the brief, clearly represent design concept. Pretty modern, okay.	Rs
8	Okay. So, looking on the floor plan. [Unclear]. This looks like a garage entrance.	Dc
9	It's utility, okay.	Sc
10	What is the height? Three, one, okay.	Sc
11	Can I change the height?	Bsc
12	Yeah, you can, yeah, if you had to.	Bsc
13	Because I'd take off the roof, could I go higher?	Bsc
14	Yeah [unclear].	Bsc
15	Okay, alright, sorry. Okay. This is North, South. Gallery space, reception. Reception, big shower room. Shower room. Kitchen, bathroom, storage.	Ss
16	Storage. Does it need to be there?	Bes
17	North, South, North, South.	Ss
18	[Unclear], hallway, stairs [one level]. Okay, the stairs would be somewhere here, probably.	Bes
19	It's one metre. Four metres, yep.	Ss
20	Kitchen, bathroom, storage, hallway. Do we need a hallway? Do we need a hallway?	Bss
21	Not necessarily.	Bss
22	Stairs. Okay, once again, customers' interaction with the space indicated more than one space.	Fs
23	Gallery design. This looks interesting, too.	Bss
24	Go in here. To have a reception somewhere here.	Fs
25	If a hallway, look through - through. This could be additional storage. [Unclear]. Perhaps an extension.	Bes
26	To have an extension on this side, so therefore PV access to the kitchen. Or here at the end. Depends.	Bsc
27	The sizes. It's about - so I try to measure about a distance. Just two, seven. Eight, eight. Okay.	Sc
28	Three six. There's a stair. Okay.	Sc
29	Six, four. What's this? Just eight hundred. Okay. So seven, eight hundred.	Sc
30	Three, six. That would be one, five. Three metres.	Sc
31	That's not much. Okay. [Unclear] the stairs and two working rooms...	Bsc
32	...off the balcony. Upper level space here. Stair comes up here.	Ss

33	Okay. Three, six, not much.	Bss
34	Stair, stair, stair, stair. Office space. Better on this side [unclear] not much space.	Bss
35	Okay. Stair sits here. ... yep. Two, three, four.	Ss
36	Direction. That way, the other way. Entrance. Tight ... Too tight. Kitchen, toilets, storage. Okay. Or here, kitchen.	Bss
37	Oh, okay. Sorry, I stopped talking again.	Ns
38	So, at the moment I tried to draw the sketch.	Ds
39	I will extend this to this with - to gain a bit more space here, I would like to have the entrance on this side.	Ss
40	Place the stair on this part, so I can use this for the area here, for the showcase.	Ss
41	But also, in the upper level for the two office spaces. So this becomes a two storey area.	Ss
42	Reception, hallway, probably kitchen next to the reception. I'm still undecided.	Bes
43	The two bathrooms here, and possibly a storage on this side.	Ss
44	I'm not quite sure about the technical room. I'll probably have to move it slightly. I'm not sure if it needs to sit in this shape.	Bes
45	I will see if I get there with the bathroom. It's a little tight at the moment. It could be also here, at the end.	Bss
46	How wide is it? I measure. Haven't measured this direction. It's one, five. Seventy five, seventy five, eighty.	Sc
47	It's possible. Okay	Bsc
48	It's possible across, not by length.	Bss
49	Then the entrance would be here, so it causes more trouble.	Bss
50	It's probably better this way, or to have the bathrooms next to each other from this side, so you don't look on the bathroom doors.	Fs
51	The storage door can be hidden pretty much. So there could be still images on the walls.	Fs
52	The question is, is that experience for space if it's only one showcase?	Bes
53	Two sides, person with full manager and will focus on the customers' interaction with the space, and its overall aesthetic appeal.	Fs
54	Perhaps it's not necessarily the task. Interaction with the space. It's not experiencing space in that sense, probably. Art gallery.	Bss
55	So if this is the showcase, I probably need to have a few walls where images will be placed. They're probably - may be an opening wider.	Bes
56	Opening. There's the wall along the stair. Probably don't need any windows here at all. Just sky lights.	Bes

57	Highlights, sorry. Perhaps some additional - not sure.	Bec
58	Well, because it's existing walls and - we don't want to rebuild everything.	Bsc
59	Probably, it makes sense to keep the walls, to increase the height with highlights,	Sc
60	to get light in, to close these openings. Yeah.	Bsc
61	So that would be at least, let's say, four metre ceiling.	Sc
62	What was the width? Three, six.	Sc
63	Possibly not, three, four metre. Possible three, five, storey height.	Bec
64	Ceiling height, three, five. So it would be like three, seven.	Sc
65	Okay. The below level can be less. So it would be - what high is it?	Sc
66	Normal storey height, two, seven or so. Can be a bit more. Two, eight - two, nine. Okay.	Sc
67	So, now I tried to transfer this. Here's the roof at the moment.	Bsc
68	I probably will change the roof anyhow, so I simply delete it now.	Dc
69	All the objects are missing. As all the objects are missing, I simply select all those first. No, I leave them because I can use this for the orientation, where I place my openings, possibly.	Bsc
70	First - but I select all windows and take them out.	Sc
71	It doesn't recognise windows. Then I do it by hand. Okay. Take out the storey and these windows.	Sc
72	This one and I take out this bar. Not sure what is here.	Bec
73	Right, okay. I will demolish this file.	Nc
74	Place a one flight stair appropriately in this direction, this direction.	Sc
75	Have to change the storey heights first. So I change it to three, seven, and the next level to, let's say, two, nine.	Sc
76	The last level will be the roof so it does not need much height.	Bsc
77	Okay. Upper level and roof. So, now I need to select all walls and change their height accordingly to - what is it?	Bec
78	Three, seven. So it will be three, five.	Sc
79	Usually the walls would be thicker, but I leave it as it is, it's not going to be a habitable space.	Bsc
80	So, what is my [slab], actually? [Unclear] three hundred.	Sc
81	I leave it, but the upper slip, there is no slip.	Bsc
82	Right. So, need to place a slip on top. So I can place walls around, theoretically.	Sc
83	So I would like to place a stair, and one flight, yes. Simple design.	Sc
84	What's the width? It should be -	Bsc
85	one metre's fine. Perhaps nine hundred is okay. The length, okay.	Sc

86	That's pretty long. Storey height is too long. Three, seven. Uh-oh. It's very long.	Bsc
87	Might that still work though	Bec
88	- and, yes, it can work. So the entrance could be somewhere here. Yeah.	Bsc
89	Let's check. Five. More than enough, that's okay. Okay, so no problem at height.	Bsc
90	So here would be an entrance door, that's fine. I turn it into an opening that is one metre wide.	Sc
91	Two, one is okay. Could be actually more than one metre.	Bsc
92	It should be an empty opening. Okay.	Bec
93	Yes, give me the empty opening option, please. Okay, I'll leave it for now.	Bsc
94	That wide. One metre.	Sc
95	Okay. So, this space is a little tight, but however, it might work.	Bsc
96	I probably also need to move the opening slightly. So I can use one metre here.	Sc
97	I then move this wall and intersect.	Sc
98	So I probably have to - I'll leave it for now.	Bec
99	I need to place an entrance door somewhere here.	Bec
100	We need to link the library, there's no objects.	Sc
101	Okay. So now I should be able to place doors also. This could be a sliding door.	Sc
102	I'm not sure if they have something like that.	Bec
103	[Unclear] sixteen, yeah, yeah. Not very pretty. Let's take a normal one. Give up.	Bsc
104	So, now furniture somehow. Desk. Okay, I'm not designing a table, no. So I'm placing a wall across to create a sort of...	Sc
105	...reception here, to have - starting from the end, possibly.	Sc
106	Taking out either this wall or keeping it for the toilet.	Sc
107	Measuring the distance.	Sc
108	Take out this wall and move it.	Sc
109	To have a distance of at least - do I need - one, eight. Seven, five. Seven, five and six. One, seven, five.	Sc
110	Okay. Why can't you just flip? Oops. Okay.	Bsc
111	So, now I want to label the rooms, but for some reason, it does not want to label any. Reception.	Dc
112	Okay, storage height is three, seven, three, five.	Sc
113	So windows could be five hundred, one metre, two, five. Distance was three, six. One metre. Two, five. Okay. Six, four.	Sc

114	What's the length?	Ss
115	Six, seven.	Ss
116	So now, I would like to have glass corners, so place the glass corner, but I need to replace the length again.	Sc
117	What was it?	Bes
118	Six, seven.	Ss
119	Because it swapped back. I need to do the same here.	Bsc
120	Six, seven. What is the length?	Ss
121	Three, seven.	Ss
122	What? Oh, okay. Is it?	Bsc
123	Change it to three, seven.	Sc
124	To the other window type, to get the corner function. I turn it on, and on.	Sc
125	Oh, no, I need only one [unclear] either side. Of course, the other one. So and that is three, seven.	Sc
126	Okay. So if we take this one out, will that get it? Where are... Give me a copy.	Bsc
127	Okay. So I changed the window. I need to drag it into position.	Sc
128	Okay. So I should have glass corners, highlights, and I would like to place an upper level here, all across.	Sc
129	So I would need to use trace and reference to see what I can actually - turn it on.	Dc
130	Where is it? Where's the palette?	Sc
131	Would like to see the level below so I can simply place some walls. I need to pick the exterior ones.	Sc
132	Then I would like to drag this a little closer.	Sc
133	Okay. That should basically become an open glass window.	Bec
134	Probably simply a glass file, I could change it into.	Sc
135	How wide is it?	Sc
136	Three, six probably. Six, four and six, four, right. So it's [unclear]. Three, two. Glass panels.	Sc
137	Hello. This is a wall. [Unclear].	Sc
138	Two, and what is the height of level two?	Sc
139	Nine ... two, seven, ... Five, fifty. That's five hundred and fifty.	Sc
140	Two. Five hundred.	Sc
141	That it is two, seven, two, nine high.	Sc
142	Okay. Why is it less?	Bsc
143	Six, four. Eight hundred. So now I would like to place into the middle, a wall.	Sc

144	So design the centre line here, to have two offices. Width of two, five. Oh, I'm sorry. Two, five and I draw a wall across and extend it. Oops.	Sc
145	So please stretch it. So this would be my office space, basically. Office one. Office two.	Sc
146	The roof garden will be here, around.	Sc
147	I have a wall. Okay. Check and [unclear]. Not there yet. Okay. So I need to extend my slip.	Sc
148	Forgot this. Why? It's there. Do I have to	Bsc
149	no? No. Okay. So my windows are too high, apparently.	Bsc
150	Why? Okay. Let's check. [Unclear].	Bsc
151	One metre. Okay. Probably enough to place window.	Bec
152	Oops, stop. So we're here and doors. What was the length?	Sc
153	One, seven, five, was it? One, six, five, zero.	Sc
154	One, seven, five. Okay. That's five zero. Let's leave it simply.	Sc
155	Window. Seven high.	Sc
156	Just seven.	Sc
157	That would be five hundred.	Sc
158	Six hundred.	Sc
159	[Let's place a wall]. Need just a wall	S
160	but it does not want to get any windows. So, what is wrong with this one? Okay. Why does it not come up in the floor plan? Why?	Bsc
161	Interesting. Okay. No window because the [coupling] is higher.	Bs
162	Okay. Same here, possibly. Let's measure first.	Sc
163	One, five,	Sc
164	let's say. Here, that would be one, nine.	Sc
165	Let's measure into the corner.	Bec
166	Two, one, three. One, six, five.	Sc
167	Okay. So I need, probably, a roof. Is this high enough?	Sc
168	My walls are too high. They need to be less.	Bsc
169	Walls, they should be two, five, I think.	Bec
170	Two seven. Okay. Oops, I missed two. Two, seven. Two, seven. Five hundred.	Sc
171	Let's do it. One hundred. Okay. What? Five hundred. Two, seven. Two, seven. Two, seven. Walls. Two, seven.	Sc
172	So you have to use it on the ground. Yes. Two, seven. Okay.	Sc
173	Let's place a roof.	Sc
174	Something's wrong with the view, so...	Bsc

175	...I try to fix the coupling, but at the moment, I can't find it. Document floor plan cut plane. It seems as if it's just justified off, offset, history. Show up to. Okay. It's so odd.	Bsc
176	Finally, I can see my openings. One metre, that's nine hundred.	Sc
177	Okay. This is correct. This is very wide.	Bsc
178	Let's make it seven, eight hundred. Okay.	Sc
179	Why doesn't it show?	Bsc
180	Okay, I draw simply lines to indicate the layout. Okay.	Dc

AMM Session: Participant H

NUMBER	UTTERANCE	FINAL CODE
1	All right, okay. So what do I need?	Rs
2	I need a - right, a reception, a big showroom, a kitchen, a bathroom, a storeroom, a hallway, stairs, from level -	Rs
3	so I think basically first I've got to figure out where I want to put the stairs.	Bes
4	What room I want to put the stairs in, that will make a difference.	Bss
5	Right, so - okay. Well, I'll get rid of the roof. Delete all the roof first and get rid of everything I don't want.	Dc
6	So obviously the front room - the front room is going to have to be the main reception	Bsc
7	well, the front room has got to be the big showroom, so that's the showroom.	Bsc
8	On the upstairs I would double that up to be a showroom as well. Then that can be down the floor. Plus a first and second floor.	Bss
9	The stairs are going into there somehow or somewhere.	Bes
10	So the stairs can go into the main showroom, so it goes straight up to the second floor into the next showroom, so there's two showrooms. So there's no going through any other room.	Ss
11	They're just from one - if you're going through an exhibition up to the next exhibition or the continuation of this exhibition.	Bes
12	This is going to be a - no sleeping, so we can get rid of the sleeping area	Ds
13	and the bathroom and that can be a - you won't need much of a kitchen. So the kitchen and the bathroom should be together somehow, because you don't need a bathroom in the reception and we do need the reception downstairs	Bss
14	More important to have the reception downstairs and probably the offices upstairs.	Bss

15	So the bottom room, what was the kitchen and we might change the size of that room because we don't need such a big reception area.	Bss
16	Yeah, I think I'll make the reception - well I don't know, do I need that smaller or bigger? I'm not terribly sure.	Bes
17	Do you need a large kitchen?	Bes
18	You have to have - if you're going to have the showroom you need access to the bathroom from the showroom so what you can do is make that slightly L-shaped	Ss
19	and you need a smaller kitchen, that's what I'm going to do,	Ss
20	and I'm going to cut out that wall there.	Ds
21	So that makes it kind of L-shaped down the bottom	Ss
22	Right, I'll follow that through upstairs. You do need a storeroom.	Fs
23	I don't think that will be a big enough storeroom. It wouldn't be a big enough storeroom.	Bss
24	You don't need a bath, do you? I mean why would a gallery need a bath?	Bes
25	So okay, cut out the bath	Ds
26	because you don't need a bath in a gallery	Bss
27	and you can [5:00] extend that storeroom. You can make the storeroom -	Ss
28	I presume I've got to keep the outside shape the same, so I keep the outside shape the same except for maybe some balcony et cetera.	Bes
29	Okay, firstly make that utility larger as a storeroom and then we'll shrink the bathroom	Ss
30	because we only need a toilet and a hand basin, you don't need anything else in the gallery.	Bss
31	That can also be dittoed upstairs. I'm not sure this is going to work. That can be the kitchen there.	Bes
32	Right [unclear] there. L-shape there and the reception can go there. Now if you're going to have - I'll just work out what floors	Ss
33	before I worry about that a piece of paper to work out upstairs.	Bes
34	Okay, I think upstairs we will have the same shape to the showroom and we'll - I think we'll keep the L-shape. We'll have some offices up there.	Ss
35	Can we make that bigger?	Bes
36	I can't see why - we'd be able to keep that on top of that.	Bss
37	So we'll have the offices upstairs.	Ss
38	We've got two salesmen; they don't need such a big office.	Fs
39	So do we have them sharing an office? I suspect we can have them sharing an office.	Bes
40	I'm making a mess out of this drawing.	Ds

41	So offices for two to share but the manager must have an office by themselves. So that's office for manager.	Fs
42	Now I made a real hash of this drawing.	Ds
43	Keep the bathroom upstairs. Do we need a bath?	Bes
44	I can't see why we'd need a bath for the bathroom so we'll just keep it there.	Bss
45	Now that gives me a horrible shape there. I don't like that shape at all.	Bss
46	Well, we can have that just as an extra storeroom. Okay, so that's an extra storeroom and that gives it a funny shape.	Bss
47	Well Jeff, I hope you don't need to see these drawings because I made a real mess.	Ns
48	Right, okay. That gives me a bit of an L-shape,	Ss
49	that gives me a straight office which can be a share and that gives me an office which can be for the manager.	Fs
50	But that gives extra wall space so in a way that's good.	Bss
51	We'll have one door there and well it's going to be the staircase there, have a staircase straight up there coming out to that. So that door can be there. Okay.	Ss
52	Now we've got a balcony don't we, a storeroom, a hallway.	Ss
53	Oh, I haven't got a hallway. Why do we need a hallway?	Bes
54	I can't see why we need a hallway. Oh well we've got to have a hallway.	Bss
55	So reception, big showroom, kitchen, downstairs, a bathroom - well, we've got two bathrooms. Storeroom - well we've got a bigger storeroom downstairs and a smaller one of recess upstairs,	Ss
56	because galleries need a lot of storeroom. Stairs from the upper level. [10:00] Now I haven't got a hallway but I can't see why I need a hallway. In fact this design wouldn't need a hallway.	Bss
57	Two workrooms with a big balcony. Oh well that goes that. Two workrooms. Well, we'll have to turn that into the workroom.	Ss
58	I think I might change my mind a bit. I'll start with - okay. We'll do this bit more consistent now I've got that thought out.	Bes
59	Okay, now we will have - the stairs and the hall - why do I need the hall, I'm not sure.	Bes
60	Okay, so I'll go back down to redesign this again.	Bss
61	I will have a square utilities room because you need a small - a really large storeroom for L-shape there.	Ss
62	Although it's an L-shape that looks clumsy it's still a good wedge of storerooms.	Bss
63	I don't like square rooms anyhow.	Bss
64	Bathroom's shrunk down. We don't need a big bathroom. That will be the same upstairs bathroom. Room with no bath.	Bss

65	We need a kitchen downstairs because of the reception and we shall have that as a small one.	Bss
66	That goes there, off that and that's the kitchen. That makes an L-shape which has got access to the bathroom, showroom. That reception has to be there.	Ss
67	Now - so the [unclear] question is where do we want the stairs?	Bes
68	That's the problem, the stairs in this design - I don't like the stairs there, I reckon that's a dumb place to have it.	Bss
69	Now if you go up there you go into - so I think I'm going to put a central staircase here. Well that takes up - if you've got wall space. The stairs near the door's a dumb one.	Ss
70	Okay, upstairs let's work it out - let's just work out quickly what we want upstairs. Work out what we want upstairs and then we'll stick the steps in.	Bes
71	Because I don't want the steps near the door, I don't like that. I don't like it there either.	Bss
72	So we've got upstairs.	Ss
73	Now we've got to have two workrooms. Have they got to be large workrooms?	Bes
74	Two workrooms. Well, the bathroom can stay in the same position, that's the only thing that's going to be constant. Now that gives us a very funny shape for there but that's okay because workrooms always need storage.	Bss
75	Now we need another storage room up here.	Bes
76	Two storage rooms because I mean art galleries can never have enough storage.	Bss
77	If you've got two workrooms - so that's the storage - another storage room.	Ss
78	Okay so upstairs we've got to have - we don't have [tag] offices. So we can turn these into two large - I just can't see why I need a hallway.	Bss
79	[15:00] The reception's downstairs, the showroom's downstairs, the kitchen's downstairs, two bathrooms, one upstairs, one downstairs. Storage space - well we need storage space for a gallery downstairs and upstairs.	Ss
80	Obviously we need stairs from the ground floor to two workrooms with a balcony. Okay, so upstairs. Well, we can have these as two workrooms.	Ss
81	I suppose that gives you the problem of having	Bes
82	okay. We'll have a hall there to the bathroom and storeroom.	Ss
83	So a hall, not where I really think is a satisfactory place but hallway there.	Bss
84	Okay so that would make these rooms - now I'll make these two rooms workroom one and workroom two.	Ss
85	Jeff, I'm making a hash of these drawings.	Ns
86	It's [unclear] that gives me -and I've got room for an extra - and the balcony from the two workrooms	Ss

87	because that's what it makes it sound like, so I'm not sure, we'll have the balcony up there. I don't know how big I'll make that, I'll wait until I just see what I'm doing.	Bss
88	This has got a staircase up here, a spiral staircase,	Ss
89	because I like spiral staircases. I'm not sure that's the best place for it but at the moment that'll do.	Bss
90	That gives me an extension. So I have two upstairs, downstairs, okay.	Ss
91	So that's still showroom [unclear] I increase my showroom size.	Ss
92	Okay, now downstairs,	Ss
93	what is that?	Bes
94	Oh that's a cupboard, so we can get rid of that.	Ds
95	Okay now - undo, undo.	Dc
96	First I'm going to save this plan and start - okay. I'm saving the original one and I'm starting another one	Dc
97	because I usually make a hash of something and I've got to have it done again, particularly before I start deleting.	Bsc
98	Okay, I'm going to delete the cupboard	Dc
99	and then I'm going to turn this storeroom	Sc
100	- get rid of the bath - get rid of the -	Dc
101	so I'm going to make that a storeroom.	Sc
102	I've got a wall. How high are these walls? Are these standard walls? Yep, right, okay. What sort of wall is it?	Sc
103	Well it's white;	Sc
104	I won't worry about the colour yet.	Bsc
105	Do I want a masonry wall?	Sc
106	I'll just have a plastered wall, that'll do. I want a door into there.	Sc
107	Now does that look like it's a big enough door?	Bsc
108	That's into the bathroom. I've probably not made it big enough.	Bsc
109	We can shrink that down.	Sc
110	Oh we've got a window there. I don't want a big window in a bathroom, not in a commercial premises.	Bsc
111	So we'll make it a small window and move it.	Sc
112	we want a door. I'm going to move that window over here. Over the hand basin.	Sc
113	Put that over there so we can put a door into there. A door, a door, a door.	Sc
114	Now what sort of door do I want? An ordinary door. A simple door. A simple door will do	Sc
115	because I'm not going to worry about inside too much.	Bsc

116	Does that mean I haven't got enough room there? Oh, I must have.	Bsc
117	Come back into the door. This is all a bit different to my set up.	Bsc
118	Where is the libraries? I can't find the bloody libraries. Doors, okay, here we go.	Bsc
119	Hinge doors. That'll do.	Sc
120	That looks like it's very - mm. Now that's not very good. It's not giving us very much room.	Bsc
121	How big is that bathroom? This only needs to be - where's my measurement.	Sc
122	Oh, I'm being terribly slow.	Nc
123	One metre, two metres across, I can just add.	Sc
124	Oh bugger, that'll do. That goes into there. Okay now you've got - this is the kitchen.	Sc
125	This is the kitchen now,	Ss
126	now you want to get rid of that wall and bring that back up, get rid of a whole	Dc
127	where's my piece of paper?	Ns
128	You want the kitchen there. Where's the kitchen? Okay. Kitchen can - parallel that line there.	Sc
129	So okay. You can go into that - oops. Go into there so you don't trip all over the door.	Sc
130	That's an awfully big door. Oh I didn't want it that side. No, you're going to have to put it over there.	Bsc
131	Okay, we'll go. Okay Jeff, because I don't normally use set doors I don't know how to change.	Nc
132	I usually make my own doors, I don't know how to change the direction of how it opens.	Bsc
133	So that's the kitchen at the back and the doors need to open the opposite way.	Sc
134	Okay, so - that can stay like that. That can stay like that.	Bss
135	Okay, so where can I put -	Bes
136	now this door can be moved over.	Dc
137	Not a great, big one.	Bsc
138	So I can put a spiral staircase in the centre there.	Ss
139	Now I don't want a door like that, I want a sliding door, but that's outside.	Bsc
140	Let's just get the floors done. All right, apart from that - okay, I think that's how I want the bottom floor to be done.	Sc
141	So I'm going to cut and paste it to go up a floor. Paste and I'm just going to change the directions of the floor spaces and then I'll change all the bits and pieces.	Dc
142	I don't want those do I?	Bsc

143	Oh the balcony, we've got to put the balcony up here too.	Sc
144	We don't want that - oh we can leave that door and leave that one.	Bsc
145	So how big do we want the balcony? Beyond that. Let's just look at the size wise.	Sc
146	Okay, we want - I'll make it concrete.	Sc
147	Good God, this is so different to mine. It's frustrating when it's different to yours. All this - there's hardly anything on this..	Nc
148	Okay, well let's just have timber - it's meant to be flooring but anyhow.	Sc
149	Okay, now. [30:00] Okay. Oh it's just - right, so upstairs. We're changing some of the rooms, [unclear] change [that first].	Sc
150	[You are too slow]. Upstairs you're going to have an increased showroom, you've got to have a hall there.	Sc
151	Not where I normally put a hall but since I've got to put a hallway, that's where it's going.	Bsc
152	In that hall, the storeroom can remain the same shape because there's an extra storeroom.	Sc
153	Galleries can never have enough storage.	Bsc
154	Bathroom can stay the same. So now we'll have a hall there	Sc
155	and we'll get rid of that door	Dc
156	because I don't like it.	Bsc
157	We've just got to work out where to put these steps. I haven't really worked that out properly.	Bsc
158	Wall. Okay. Move that over there, move that wall over there. So there's the two workshops.	Sc
159	Okay, the doors are all in the wrong place now. Okay, so have we got all our bits that we need?	Bsc
160	Okay. I've got my floor plan right, I think. Probably not ideal.	Bsc
161	The kitchen - you don't need a huge kitchen but you need a serviceable kitchen.	Bsc
162	The storeroom's going off the kitchen, which is not great.	Bsc
163	I could actually - no, if I do that - if I go upstairs. Okay. If this is a gallery the best thing is to have this - you need the more wall space.	Bec
164	Yeah, the more wall space the better you have.	Bsc
165	So you could actually put the staircase - if you have a spiral staircase - in the middle of the room which expands your capacity on the walls.	Sc
166	It might impede, if it's got a - but there's no point tucking it away into a corner.	Bsc
167	So that gives us maximum spaces. Well, let's have a look. We've got - that looks pretty crap that veranda	Bsc
168	and we've got to get rid of those windows.	Dc

169	I hate pokey little windows.	Bsc
170	Now the storeroom's got a big window,	Sc
171	we can get rid of that.	Dc
172	That's the top floor. We don't want a big window for the top floor storeroom; we just want a small one. We need only a small window.	Bsc
173	Oh I don't even know what sort of window that is. A simple window, that'll do	Sc
174	Okay, we can even shrink that because I mean it's a storeroom, it doesn't need anything else. [Unclear].	Bsc
175	Okay, we'll get rid of these pokey little windows upstairs and	Dc
176	we'll have some big, glass windows, because these are meant to be workrooms. Big, big, big windows.	Sc
177	No, we'll make them slide doors. Sidelights, double door with - not wanting to muck around with the windows too much, I'm going to put these great big ones in which take up	Sc
178	oh no, I want slide;	Bsc
179	they've got to be slide. Oh sliding doors,	Sc
180	I'm in the wrong thing. Okay	Nc
181	God, these don't look like ordinary slide doors, top flat slide doors. [35:00] I just want slide doors.	Bsc
182	Garage doors. Slide doors, where are ordinary slide doors? Oh that'll do.	Sc
183	I don't know what that looks like, it probably looks a bit crap. Oh that's not too awful.	Bsc
184	The same with downstairs. We'll have the same windows downstairs.	Sc
185	Well the kitchen doesn't need it. This is the reception, that can [unclear]. The kitchen doesn't need - right. Okay.	Bsc
186	So in the reception we've got a large window out, the kitchen we only need two smaller windows.	Sc
187	Make that - move that and have - oh you can have a long window. Oh, I don't know. I don't think it should be that long. It's far too high. How does that look? [Unclear].	Bsc
188	Okay, front - bathroom, storeroom, front, spin it round.	Sc
189	More light.	Bsc
190	Let's go back to this paper. Why are we going - we should have - right the entrance, let's look at the entrance to the shower room.	Ss
191	I don't want the shower room at the front. This is meant to be a commercial premises so we don't want the door at the side,	Bsc
192	we've got to have the door at the front. Right.	Sc

193	Okay, firstly let's get rid of these little windows and the door at the side, the same with upstairs. So we're down on the ground floor. Let's go here, okay.	Dc
194	We're going to put this - because it's a shower room we're going to put a spiral staircase and maximise our wall space. That's all we need to do is maximise the wall space in both downstairs and upstairs.	Bss
195	Now downstairs we maximised our wall space here, the L-shape, so I still think we can stick it in the centre there which gives us a lot more exhibition space.	Ss
196	Now we want to have windows all along. Now we should have windows all along the front and the entrance in the front.	Ss
197	Oh that minimises our space doesn't it? Damn it. Well, okay.	Bss
198	You do need to see in if it's a commercial premises. So you do need glass there whether you like it or not.	Bes
199	That's where you can put stands in the [40:00] front but maybe not upstairs	Bes
200	So let's have some windows. Oh and some sliding - oh God, they've got crappy sliding doors in here.	Sc
201	I don't like any of those horrid things. Okay, let's go - maybe they're in windows. I've got no idea. It's this horrible set up, I don't like it.	Bsc
202	I can't find anything in this. Windows. Sliding windows, that's what we wanted.	Bsc
203	That's what I would call a door, okay.	Sc
204	There, that's what we want, big, sliding windows. Okay. We'll see how that goes	Bsc
205	Okay, I've got big sliding windows here now. I want to move that along here. Multiply that by one.	Sc
206	We'll cut out the window at the side because that - so we cut that window at the side.	Dc
207	We do need a door. Now hold on, let's - okay; now I'm going to change because now I've found the right windows, I think I've found the right windows.	Bsc
208	Oh they're pretty crappy. Oh it doesn't matter. I'm going to have that up there.	Bsc
209	Balcony. We need a door at the front. Again it has to be glass.	Sc
210	That will look hideous.	Bsc
211	Okay, what am I doing now? Telling it to shrink but it won't shrink. Okay, that's a better window. Let me have a look.	Bsc
212	So I put in lots of windows at the front	Sc
213	but because it's a gallery I don't want any windows at the sides because that would take away the wall space.	Bsc
214	Now we need to go upstairs. Again, we want to maximise our wall space. [45:00] This is going to be a really ugly house.	Bsc

215	So we want to get some windows. Here I'm going to have a four sash window but I want them high off the ground so we can maximise our space.	Sc
216	So 1500, I only want them about - I only want them narrow so they can be up high.	Sc
217	I'll see how this looks, it's probably going to look dreadful but anyway. Galleries aren't meant to be pretty. Okay. I think that is actually more utilitarian.	Bsc
218	We could actually raise those a little bit higher I think. Again, we can put one on the side. We can probably put two on the side there, okay. Up higher.	Sc
219	Okay, now what have I got? I'm maximising my space now and so I'm going to do that at this side. So okay, where's window.	Sc
220	Okay, why don't we have a look?	Dc
221	We can do those down the bottom as well. Right. Go down to the bottom floor.	Sc
222	We've now got - right, now as far as light goes we've got plenty of light in there and we've got the front -	Sc
223	because we needed an art gallery we've got lots of light inside, probably not ideal.	Bsc
224	Now we need to put some stairs in. I'm going to put the stairs in the centre of the room so it will maximise the wall space.	Sc
225	Okay. We haven't got the doors up there yet but we'll worry about that. Oh God, I forgot about the staircases, I hate these.	Bsc
226	Okay, staircases. I think we've got - height is that - we're just going for a basic circular one.	Sc
227	Rails, where's our rails? Height - again, I'm not going to change too many things here because I'll be all right. Oh it seems awfully big.	Bsc
228	t's a very small room. Let me have a look. Oh goodness. Oh I don't know, that could be quite unique. I think I'll just marquee that. I don't think that needs to be quite as big.	Bsc
229	Okay, if you're going to do that you're blocking the window. So take this wall over here. This window - move that window across.	Sc
230	[50:00] I believe that could be slightly smaller. Oops.	Bsc
231	Okay, let's cut a hole in [unclear].	Dc
232	Go up the stairs. Oh damn it. Oh. I hate cutting holes, they always muck up on me. Start again. Oh why aren't you working? Why am I trying to rush too much? Ah God, why did you work this time? Okay. I'm not going to muck around with the railing too much.	Bsc
233	Now I need to think about some doors for up here as well. Obviously you want them on the other sides of the staircase.	Sc
234	I like a spiral staircase but that is an awfully big one.	Bsc

235	Anyway, too late now. I want some doors. If we have work space up the top there do you want to see into the workshops? Probably not.	Bsc
236	Okay, you've got maximised showcase rooms, you've got a small hall, you've got two small -	Sc
237	haven't got a window for the storeroom, top storeroom. Do I need one? Well, I'll put one anyhow.	Sc
238	Oh damn, I just forgot I've still that that big window.	Bsc
239	Window, where's the standard window? Just an ordinary window, basic window, basic window.	Sc
240	I'm not changing any material here because I haven't had time. Okay, basic window's far too big for that. It's only a storeroom so we don't want [unclear].	Bsc
241	Okay, let's - okay. Okay, now we have a rather ugly looking [place] [55:00] thing so we have to jazz it up a little bit - oh that window's right up there. I think it's fairly functional as an art gallery but it is fairly ugly.	Bsc
242	Okay. Now we have a particularly ugly looking house - I mean a particularly ugly looking building but it would work as a gallery. It will work as a gallery but it is ugly.	Bsc
243	Okay, let's go to the ground floor and get some patio outside. We've got to have a patio outside.	Sc
244	Slab. Okay, not going to change the material too much. Oh bugger. Okay, what am I doing now? Oh I've [unclear]. Oh. Oh damn it, I did the wrong floor. I've been working on the wrong floor.	Bsc
245	Go to the upper floor. I'm just going to try and make this look a little bit prettier. Not that it could look pretty, it looks very ugly.	Bsc
246	Okay, just getting rid of the gap between the first and second floor because I just cut and paste it, and that's not exactly how I would	Dc
247	so - and I'm going to leave the material all the same. Again, it's not a material I would choose. Oh it's another hundred back here and another hundred. [60:00]	Sc
248	Okay. Okay, now because I did that I've got to bring up all the windows and everything else, which is a nuisance. I should have thought to do that earlier. Anyhow, too late.	Bsc
249	I've just got to elevate all the windows 300. That'll be that. Okay.	Sc
250	Now that looks better. It's still a very ugly looking house. Okay, now would that work inside as an art gallery with two workshops and two - okay. I think that would work functionally, though extremely ugly.	Bsc
251	Now let's work on the veranda. Very, very ugly veranda. I want a bigger one than that. So I'm going to [unclear].	Bsc

252	Okay. I need a rail around there. Now I'm just going to put a rail around the veranda.	Sc
253	Oh that looks terrible. Okay, I can't find any present rails so I'll just make my own because I don't know where they are and I always pre-make my own.	Bsc
254	Seven. How high did I make that? Current floor. What the hell was that? [65:00] Poured concrete - surface poured concrete.	Sc
255	I don't know if I can find it.	Bsc
256	Surface poured concrete, you will do. It will be 150	Sc
257	and it'll be - oops I'm not speaking, am I?	Nc
258	I'm putting an ordinary roof on.	Sc
259	Basically because I need to hurry up a bit and I put it far too high. I thought I had that on the right settings, on the second floor.	Bsc
260	Oh damn. All right, I'll do that again. Roof, okay, roof started again. Now I have an unsupported - yes, I'm not going to do a flash roof	Sc
261	because the design doesn't suit it. Why aren't you letting me do it? What is wrong with that?	Bsc
262	[Unclear] is zero. Do it again.	Sc
263	I don't know why it's not letting me do that but I'll try it again. Now I've got to think about what I've got to do with the veranda. Oh God, what has happened? Why are you doing that to the current story? Oh forget about that, the roof is playing up, it won't work.	Bsc
264	[70:00] Okay. For some reason the roof has gone up nine metres and won't let me remove it.	Sc
265	Oh bugger. How do you stop that? I don't know what happened there, it's still not right. Oh no.	Nc
266	Well the roof is insisting on staying up a couple of metres and I can't get it down. So I'll work on something else.	Nc
267	Okay, now I've got to work out the veranda. Put some columns on the veranda. So I need to go up to ground floor and they're about 200 high, I want them round, I want them quite substantial.	Sc
268	That's probably still [unclear] and I'll keep them in poured concrete, because I like poured concrete.	Sc
269	Okay, got to have a patio out there now. And a path to the door. Then you can have some grass, of course,	Sc
270	I like it, and some flowers, to hide what an ugly building it is.	Bsc
271	Now okay. Now [unclear]. Okay it's a utilitarian building, it's not a pretty building, but it would work very well as an art gallery.	Bsc

Appendix 6: Co-author Statement for paper one

As co-author of,

Paper One: A method to investigate differences of sketching before and during CAD modelling design process,

1. **Anthony Williams**, attest that this paper represents **Yi Teng Shih** contributed all text, tables and figures.

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Bibliographic Reference: Shih, Y. T., Williams, A. and Gu, N. (2011) A method to investigate differences of sketching before and during CAD modelling design process. *Proceedings of the 2011 International Conference of the Association of Architecture Schools of Australia (AASA 2011)*, Geelong, Australia, pp. 308-318 (ISBN 978-0-9581925-5-2)

Appendix 6: Co-author Statement for paper one

As co-author of,

Paper One: A method to investigate differences of sketching before and during CAD modelling design process

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Appendix 6: Co-author Statement for paper two

As co-author of,

Paper Two: A switching coding scheme for exploring design cognition in mixed media design environments

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Appendix 6: Co-author Statement for paper two

As co-author of,

Paper Two: A switching coding scheme for exploring design cognition in mixed media design environments

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Appendix 6: Co-author Statement for paper two

As co-author of,

Paper Two: A switching coding scheme for exploring design cognition in mixed media design environments

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Date signed	31 January 2017

Full name of the Assistant Dean Research Training (ADRT) University of Newcastle	
Signature of ADRT	
Date signed	

Bibliographic Reference: Shih, Y. T., Williams, A., Gu, N. and Lee, J. H. (2011) A switching coding scheme for exploring design cognition in mixed media design environments. Proceedings of the 45th Conference of the Australian and New Zealand Architectural Science Association (ANZAScA 2011), Sydney, Australia, (ISBN 978-0-9581221-3-9)

Appendix 6: Co-author Statement for paper three

As co-author of,

Paper Three: Using FBS ontology to analyse and compare designers' reasoning processes in SMM and AMM design environments: A pilot study with architectural designers

3. **Mark Taylor**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

Full name of co-author	Professor Mark Taylor (co-supervisor), School of Arch and Built Env, University of Newcastle
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Signature of PhD candidate (Yi Teng Shih)	
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Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2013) Using FBS ontology to analyse and compare designers' reasoning processes in SMM and AMM design environments: A pilot study with architectural designers. M. A. Schnabel and J-Y Tsou (eds.), *Cutting Edge in Architectural Science: Proceedings of the 47th International Conference of the Architectural Science Association (ASA) 2013*, Hong Kong, pp 123-132 (ISBN 978-0-9923835-0-3)

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As co-author of,

Paper Three: Using FBS ontology to analyse and compare designers' reasoning processes in SMM and AMM design environments: A pilot study with architectural designers

1. **Willy Sher**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

Full name of co-author	Associate Professor Willy Sher, School of Arch and Built Env, University of Newcastle
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Appendix 6: Co-author Statement for paper four

As co-author of,

Paper Four: Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers

1. **Mark Taylor**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

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Date signed	24 January 2017

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Date signed	20/03/2017

Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2015) Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers. *International Journal of Architectural Research*, volume 9, issue 3 (Scopus)

Appendix 6: Co-author Statement for paper four

As co-author of,

Paper Four: Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers,

1. **Willy Sher**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

Full name of co-author	Associate Professor Willy Sher, School of Arch and Built Env, University of Newcastle
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Full name of the Assistant Dean Research Training (ADRT) University of Newcastle	
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Date signed	

Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2015) Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers. *International Journal of Architectural Research*, volume 9, issue 3 (SCI)

Appendix 6: Co-author Statement for paper five

As co-author of,

Paper Five: The roles of design media for teaching architectural design,

1. **Mark Taylor**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

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Date signed	20/03/2017

Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2017) The roles of design media for teaching architectural design. *Journal of Architectural and Planning Research* (SSCI) (under review)

Appendix 6: Co-author Statement for paper five

As co-author of,

Paper Five: The roles of design media for teaching architectural design,

1. **Willy Sher**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

Full name of co-author	Associate Professor Willy Sher, School of Arch and Built Env, University of Newcastle
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Full name of the Assistant Dean Research Training (ADRT) University of Newcastle	
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Date signed	

Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2017) The roles of design media for teaching architectural design. *Journal of Architectural and Planning Research* (SSCI) (under review)

Appendix 6: Co-author Statement for paper six

As co-author of,

Paper Six: Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes

1. **Mark Taylor**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

Full name of co-author	Professor Mark Taylor (co-supervisor), School of Arch and Built Env, University of Newcastle
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Date signed	20/03/2017

Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2017) Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes. *Design Studies* (SCI) (In press)

Appendix 6: Co-author Statement for paper six

As co-author of,

Paper Six: Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes,

1. **Willy Sher**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

Full name of co-author	Associate Professor Willy Sher, School of Arch and Built Env, University of Newcastle
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Signature of PhD candidate (Yi Teng Shih)	
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Full name of the Assistant Dean Research Training (ADRT) University of Newcastle	
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Date signed	

Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2017) Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes. *Design Studies* (SCI) (In press)

Appendix 6: Co-author Statement for paper seven

As co-author of,

Paper Seven: A comparison of designers' reflections of designing using sketching and CAD modelling,

1. **Mark Taylor**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

Full name of co-author	Professor Mark Taylor (co-supervisor), School of Arch and Built Env, University of Newcastle
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Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2017) A comparison of designers' reflections of designing using sketching and CAD modelling. *Research in Engineering Design* (SCI) (with editor)

Appendix 6: Co-author Statement for paper seven

As co-author of,

Paper Seven: A comparison of designers' reflections of designing using sketching and CAD modelling,

1. **Willy Sher**, attest that this paper represents **Yi Teng Shih**'s original research and that he contributed all text, tables and figures.

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Signature of PhD candidate (Yi Teng Shih)	
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Signature of primary supervisor (Associate Professor Willy Sher)	
Date signed	17 March 2017

Full name of the Assistant Dean Research Training (ADRT) University of Newcastle	
Signature of ADRT	
Date signed	

Bibliographic Reference: Shih, Y. T., Sher, D. W. and Taylor, M. (2017) A comparison of designers' reflections of designing using sketching and CAD modelling. *Research in Engineering Design* (SCI) (with editor)