



Designers' Reflections on Two Methods of Using Design Media for Learning Design Processes

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Abstract. In this paper we question whether switching behavior impacts on the manner in which CAD modelling and sketching 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 two assessments: design issue distributions and design process distributions. In addition, eight participants were subsequently interviewed about their design reflections after finishing design tasks. Six out of eight participants strongly believed that switching behavior is essential to make use of the advantages from both media, and to use each one to counter the weaknesses of the other.

Keywords: CAD modelling, design education, design process, design reflection.

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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 globalization of architecture, engineering and construction (AEC) projects. In empirical studies conducted by Chen [6] and Ibrahim and Rahimian [20], designers were asked to initially use traditional sketching before shifting to computer-aided design (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 [28] 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' [9, P396]. 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 [20] compared traditional sketching, 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 [20], [28]. This reflects the design industry's preference and consequently the most popular design tools employed by contemporary design schools. Chen [6] 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 utilizing AMM to explore the roles of sketching and CAD modelling and designers' reflections. This paper addresses these issues by comparing two different methods of interacting with sketching and CAD modelling (SMM vs AMM) during the design process.

2 LITERATURE REVIEW

In recent years CAD has emerged as a design tool that is capable of developing conceptual designs [27]. 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 [25]. 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 [23].

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 [5]. 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 [10]. Moreover, the accurate visualisations made possible with CAD modeling may help designers to alter and refine their design thinking [27].

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 [22]. 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 [19]. Suwa and Tversky [29] 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 [18].

Won's [33] 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. However, 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. [28] 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 [6], 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 solutions.

Ibrahim and Rahimian [20] 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. Our objectives are to test whether there are differences between the SMM and AMM methods and how switching behaviour could impact on designers' reflections.

3 RESEARCH METHODOLOGY- PROTOCOL ANALYSIS

There are two ways to report protocol data: retrospective and concurrent (think-aloud) verbalisation [8]. 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 [24]. 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 [24]. 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 [30], [31]. 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 [15]. 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 [11], [21]: (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.

3.1 Using the FBS Coding Scheme to Code Sketching and CAD Modelling by SMM and AMM Methods

Gero's [12] 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 [14]. 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 [30]. 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.

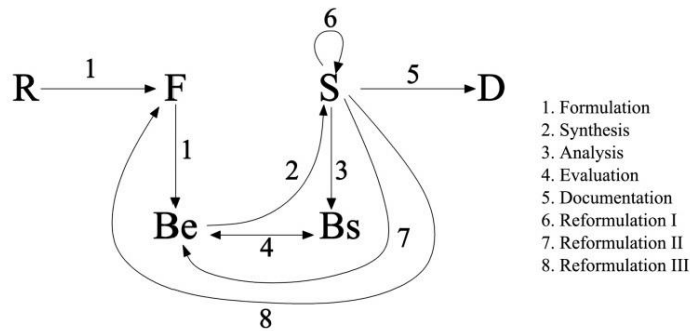


Figure 1: FBS coding scheme [14].

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 [13], [14]. 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 [12].

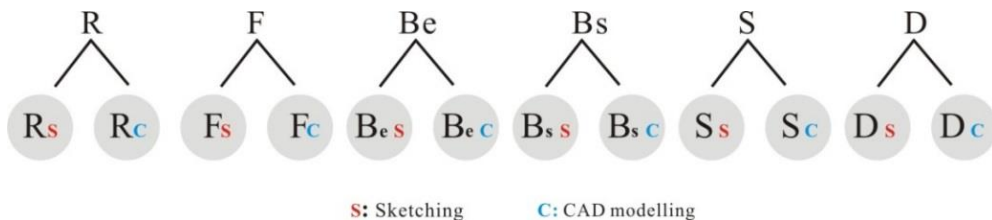


Figure 2: Development of the FBS design model for coding sketching and CAD modelling activities.

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 2). 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 analyzed.

3.2 Participants Recruitment and SMM and AMM Experiment Set-ups

Designing is a high-level cognitive activity. Most of the empirical research into designers' behaviors includes a relatively small number of participants and seeks to understand specific cognitive processes [1], [2]. 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 practicing 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 [7]. 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). 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.

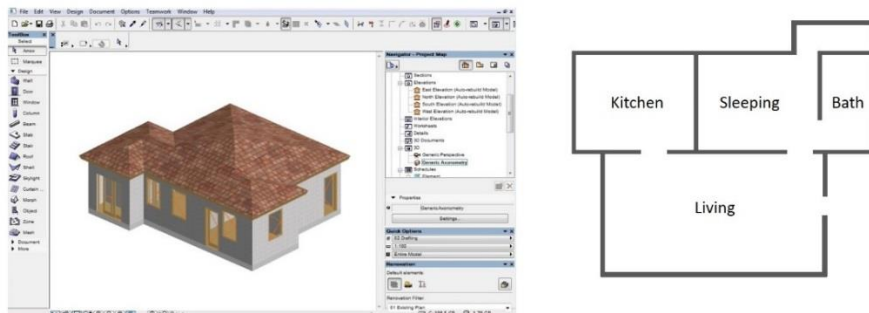
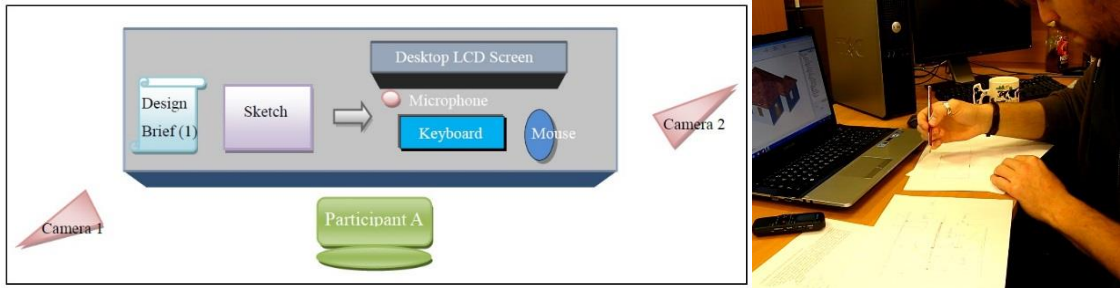
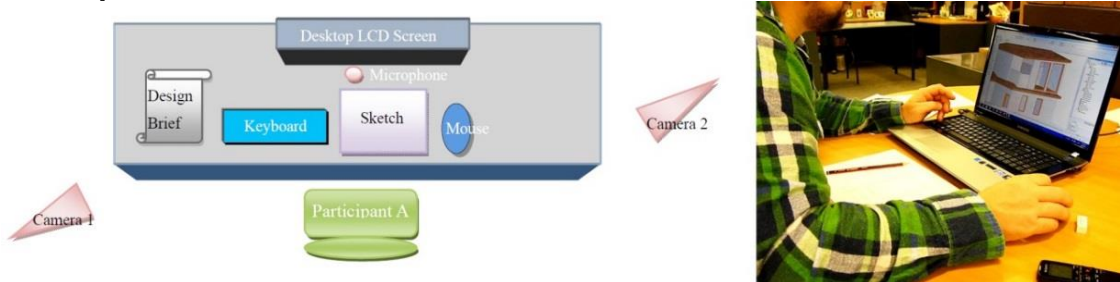



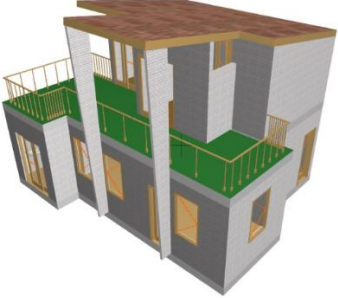


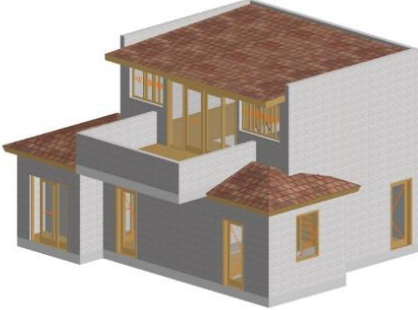
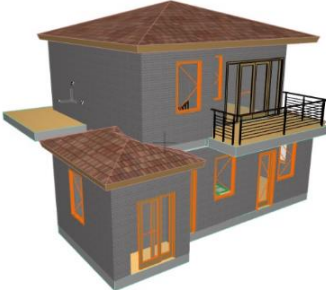

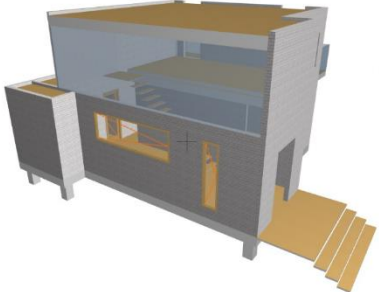
Figure 3: The experimental CAD model with its 2D layout.

Figure 4 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 4:** SMM and AMM experiment set-ups.**4 DATA AND DISCUSSIONS**

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) [17]. 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 [13]. In Bilda et al.'s protocol studies [3], [4], 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 [16] claimed that utilizing 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 [4]. All participants completed a design based on the briefs allocated to them (Table 1, next page), 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 designers' reflections.

| Designers | SMM sessions | AMM sessions |
|-------------------|---|--|
| Designer-A |  |  |
| | Task: Architecture office design | Task: Dream house design |
| Designer-B |  |  |
| | Task: Architecture office design | Task: Dream house design |
| Designer-C |  |  |
| | Task: Art gallery design | Task: Architecture office design |
| Designer-D |  |  |
| | Task: Dream house design | Task: Art gallery design |

Designer-E

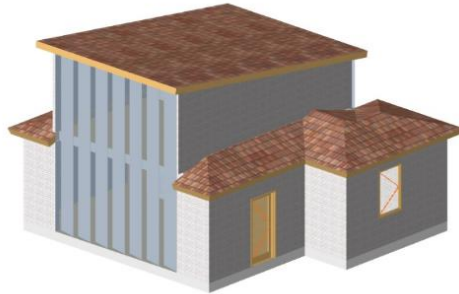


Task: Architecture office design



Task: Dream house design

Designer-F

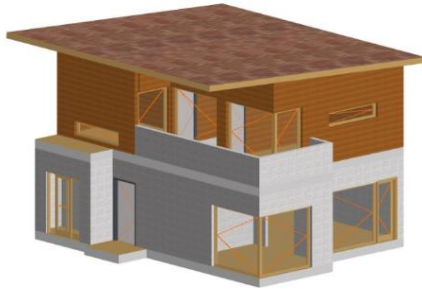


Task: Art gallery design

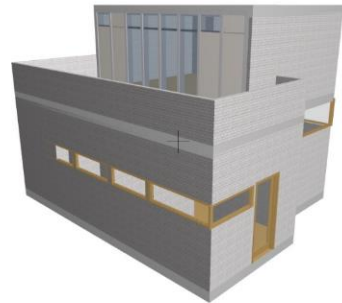


Task: Architecture office design

Designer-G



Task: Dream house design



Task: Art gallery design

Designer-H



Task: Dream house design



Task: Art gallery design

Table 1: Design outcomes from eight designers on SMM and AMM methods.

4.1 Comparison of FBS Design Issue Distributions between SMM and AMM Methods

Each design session's occurrences of design issues in SMM and AMM were normalized by dividing them by the total number of design issues in that session (Table 2 & Table 3). All participants had similar aggregated design issue distributions for sketching and CAD modelling in SMM and AMM. In both SMM and AMM, it was noteworthy that the percentages for design issues of requirement (R), function (F) and expected behavior (Be) in sketching were slightly higher than in CAD modelling. In contrast, the percentages of design issues of behavior 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 behavior 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 behavioral patterns using sketching and CAD modelling.

| | | Participants in SMM | | | | | | | | | | |
|---------------|--------|---------------------|-----|-----|----|----|----|----|----|------|------|------|
| No. of issues | design | 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 | 0.0 |
| | 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 2: Normalized number of design issues and their aggregated distributions (%) in SMM.

| | | Participants in AMM | | | | | | | | | | |
|---------------|--------|---------------------|-----|----|----|----|----|----|----|------|------|------|
| No. of issues | design | A | B | C | D | E | F | G | H | Mean | SD | (%) |
| Sketching | R | 4 | 5 | 6 | 3 | 3 | 5 | 5 | 2 | 4 | 1.4 | 5.0 |
| | 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 | 9.0 | 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 |

Table 3: Normalized number of design issues and their aggregated distributions (%) in AMM.

4.2 Comparison of FBS Design Process Distributions between SMM and AMM Methods

A syntactic design process is one that presumes all segments are cognitively related to their immediately preceding segment. They are design processes which transform from one segment to the other [32]. Figure 12 shows participants shared very similar design process distributions in SMM and AMM (Figure 5). 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%).

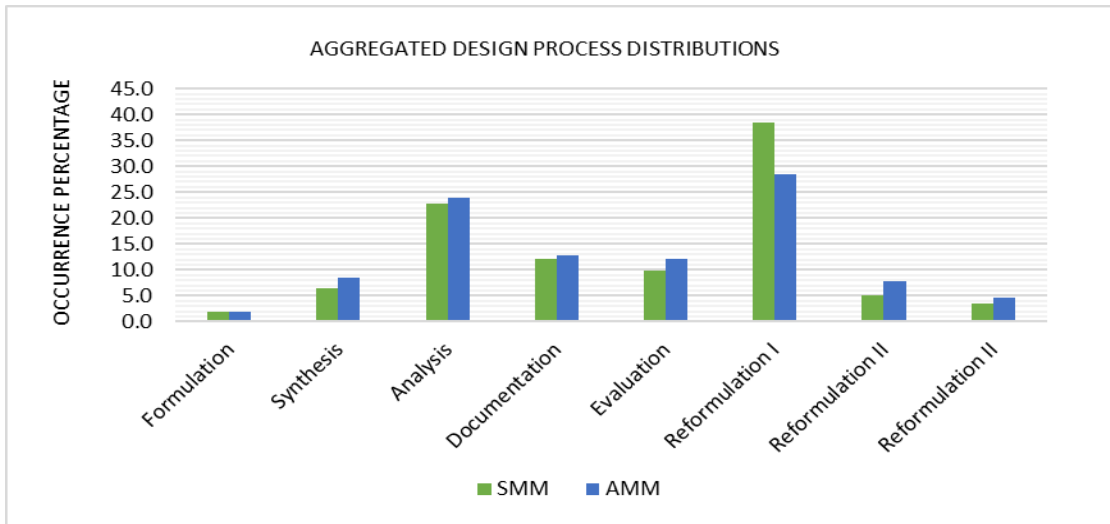


Figure 5: Aggregated design process distributions (%) in SMM and AMM methods.

4.3 Time Spent on Design Media and Number of Switches

All designers spent between 60 and 75 minutes to complete each task. In SMM, designers spent an average 25 minutes sketching their ideas and then using CAD for documentation. In AMM, designers switched between design media at will. Table 4 shows switching examples with their reasons.

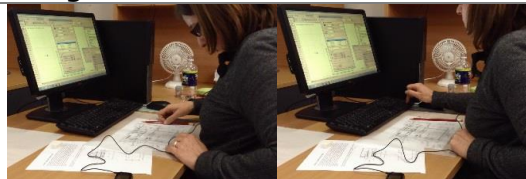

| Designers' switches | Reasons |
|---|---|
|  | 'Referring to the sketch and continuing modelling in CAD.' |
|  | 'Still trying to resolve the staircase I wanted to maximise the walls because it was meant to be an art gallery and I decide to stick it in the centre of the room so it would give the absolute 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.' |

Table 4: Switch examples with reasons.

Table 5 lists the number of switches for each designer. Based on the think-aloud protocol and the FBS coding scheme, the differences between SMM and AMM cannot be identified. Additional studies are needed to devise code schemes that enable analysis of the impact of switching.

| Designers | A | B | C | D | E | F | G | H |
|--------------------|----|----|----|----|----|---|---|---|
| Number of switches | 16 | 20 | 17 | 14 | 15 | 8 | 7 | 5 |

Table 5: Number of switches.

5 DESIGNERS' REFLECTIONS

Although this study has shown that there were no significant differences between SMM and AMM in terms of design issue 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.

5.1 Designers' Reflections on SMM

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 behavior. 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 needs to 'fix' encountered problems on the screen and not draw by hand possible alternative solutions. This process is much slower than returning to the 'thinking hand' for developing new ideas'. (Participant B)

5.2 Designers' Reflections on AMM

Eight participants provided their reflections of AMM and these have been categorized into two aspects: the roles of design media and switching behavior, and their merits throughout the design process. Each design medium has its advantages and disadvantages. More importantly, the role of switching behavior 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 [20] and Sachse et al.'s [28] 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)

6 CONCLUSIONS

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', [9, P396] and that such usage would actually engage designers' thinking along creative pathways. All participants believed strongly that AMM was an ideal approach for conceptual design. Three contributions were summarized from this research: (1) help designers make appropriate design decisions; (2) help enhance designers' cognitive thinking on co-evolution; and (3) help designers make a natural design workflow.

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 propose a new way of using available design media (i.e. sketching and CAD modelling) involving switching behaviors 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.

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