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

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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 [2] and Ibrahim and Rahimian [8], 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 [10] 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' [3, 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 [8] 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 [8], [10]. This reflects the design industry's preference and consequently the most popular design tools employed by contemporary design schools. Chen [2] 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 designers' reflections. This paper addresses these issues by comparing two different approaches of interacting with sketching and CAD modelling (SMM vs AMM) during the design process.

Protocol Analysis:
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 [8], [9], [11] show that protocol analysis can comprehensively record designers' reasoning during the design process rather than simply relying on their design results for such insights. Many protocol design studies have adopted the FBS model to describe design processes and tasks [5]. 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 [7]. 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 situates designing in terms of six design issues: requirements, functions, expected behaviours, behaviours derived from structures, structures and documentation.

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' behaviors includes a relatively small number of participants and seeks to understand specific cognitive processes [1]. 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) competence in both sketching and CAD modelling; (2) a tertiary degree in architecture with a minimum of two-years of professional architectural practical experience; and (3) competence in practicing and communicating design in English.

Architectural designers often design buildings and this study provided a basic floor plan with its CAD model. 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.

Data and Discussions:

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) [4]. 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 [6]. All participants completed a design based on the briefs allocated to them, 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. 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 1 & Table 2).

		Participants in SMM										
No. 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

Tab. 1: Normalized Number of design issues and their aggregated distributions (%) in SMM.

Participants in AMM											
No. 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

Tab. 2: Normalized Number of design issues and their aggregated distributions (%) in AMM.

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

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 then returning to the 'thinking hand' for developing new ideas'. (Participant B)

Designers' Reflections on AMM

Eight 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 [8] and Sachse et al.'s [10] 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)

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', [3, 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 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:

[1] Akin, Ö.; Moustapha H.: Strategic use of representation in architectural massing, Design Studies, 25(1), 2004, 31-50. https://doi.org/10.1016/S0142-694X(03)00034-6

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

[3] Do, E. Y. L.: Design sketches and sketch design tools, Knowledge Based Systems 18(8), 2005, 383-405. https://doi.org/10.1016/j.knosys.2005.07.001

[4] Gero, J. S.; Kan, J. W. T.; Pourmohamadi, M.: Analysing design protocols: Development of methods and tools, *in* A Chakrabarti (ed*),* Research into Design*,* 2011, 3-10.

[5] Gero, J. S.; Kannengiesser, U.: The situated Function-Behaviour-Structure framework, Design Studies, 25(4), 2004, 373-391. https://doi.org/10.1016/j.destud.2003.10.010

[6] Gero. J. S.; McNeill, T.: An approach to the analysis of design protocols, Design Studies, 19(1), 1998, 21-61. https://doi.org/10.1016/S0142-694X(97)00015-X

[7] Gero, J. S.; Tang, H.: The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of design protocols, Design Studies, 22(3), 2001, 283-295. https://doi.org/10.1016/S0142-694X(00)00030-2

[8] Ibrahim, R.; Rahimian, F. P.: Comparison of CAD and manual sketching tools for teaching architectural design, Automation in Construction, 19(8), 2010, 978-987. https://doi.org/10.1016/j.autcon.2010.09.003

[9] Kim, M. J.; Maher, M. L.: The impact of tangible user interfaces on spatial cognition during collaborative design, Design Studies, 29(3), 2008, 222-253. https://doi.org/10.1016/j.destud.2007.12.006

[10] Sachse, P.; Leinert, S.; Hacker, W.: Designing with computer and sketches, Swiss Journal of Psychology, 60(2), 2001, 65-72. https://doi.org/10.1024//1421-0185.60.2.65

[11] Suwa, M.; Tversky, B.: How do designers shift their focus of attention in their own sketches? In Anderson, M., Meyer, B., Olivier, P. (eds.) Diagrammatic Reasoning and Representation, Berlin: Springer, 2001, 241-260.