The Third International Conference on Design Creativity (3rd ICDC)
ISBN 978-1-904670-60-5
Bangalore, India, 12th-14th January 2015

INFLUENCES OF INTEGRATING TOUCH SCREEN SMART BOARD AND CAD IN COLLABORATIVE DESIGN

G. V. Annamalai Vasantha[1], H. P. Ramesh[2], C. M. Sugavanam[2], A. Chakrabarti[2] and J. Corney[1]

[1]Design Manufacture and Engineering Management, University of Strathclyde, Glasgow, UK
[2]Centre for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India

Abstract: Although a digital design tool like CAD has a strong influence on creative design, it is merely used in the detail design stage to present the visualized final product in 3D space. Limitations in CAD have led to the great emphasis on employing supporting tools in early stages of conceptual design. This paper aims to comprehend the need for supporting tools with CAD package in the design process. To understand the role played by a supporting tool in collaborative design, six laboratory experiments involving six pairs of designers working on three different design problems were conducted in the original and redesign phases. Designers were provided with Rhinoceros® CAD design tool and a SMART Board™ Interactive Whiteboard with SMART Notebook™ software as supporting tools. A significant finding from the video protocols and captured documents analyses is that there is a strong negative correlation between frequency of transactions between these two tools and the quality of final designs generated.

Keywords: *Collaborative design, Design quality, Design Tools – CAD and Smart board*

1. Introduction

Design tools play an important role in the design process, by allowing designers to express their intent externally. Any constraints imposed by design tools in this explication process could greatly impact design outcomes. Currently CAD software is the most frequently used medium in designing, but less so at the conceptual stage (Robertson & Radcliffe, 2009). The merits and demerits of free-hand sketches and CAD are widely reported in literature (Vasantha et al., 2013). In the product development lifecycle process, the transitional and iterative conceptual phase is identified as a potential knowledge-loss period (Ibrahim & Paulson, 2008). Further, design creativity is impacted in using existing CAD software (Ibrahim & Rahimian, 2010). These issues are further amplified in a collaborative environment where two or more designers work together with different tools. There is a need for collaborative conceptual tools that will provide seamless integration with CAD software to facilitate transfer of design outcomes across the design stages, starting from requirements identification to detail design stage. This should avoid content loss, and wastage of time in transferring traditional media content (e.g. paper and pencil) into digital forms.

In many collaborative design environments developed, the touch screen smart board is identified as an essential tool. The smart board is a large display unit (projected computer screen from a projector) which has electronic markers, eraser, and writing, typing and drawing capabilities. It controls the computer by touching the smart board screen, and captures and saves data. Virtually any document for discussion can be displayed and annotated on the smart board. It helps designers to stand at the screen and manipulate the model by turning on and off features to show only those parts that are relevant for discussion. The key merit is that it enables a more natural style of interaction without any intermediate devices such as a mouse. Most of the studies in the design literature used the smart board for reviewing design progress, discussing design issues, and brainstorming design solutions. However, there is a gap in understanding the potential of the smart board in conceptual design, and illustrating the content loss occurred during ideas transfer from the smart board to CAD software.

The aim of this work is to study how well a smart board supports the design process, and to understand the issues observed while transferring the smart board content to CAD software. To fulfil this aim, laboratory experiments were conducted using a SMART Board™ Interactive Whiteboard with SMART Notebook™ software (Smart Technologies Inc., 2014) and Rhinoceros® CAD software in this study. The captured documents and video protocols from the design experiments are analysed to fulfil the research aim. The rest of this paper is structured into related literature, research hypotheses and methodology, results, and discussion and future work sections.

2. Related Literature

Many collaborative design environments incorporate smart board as an important tool required to facilitate the design process. Rowe et al. (1998) detailed the Collaborative Engineering Design and Analysis Room (CEDAR) facility to demonstrate the NASA Technology initiatives for an Intelligent Synthesis Environment. The CEDAR is a conference room environment with a Windows NT workstation connected to the big screen Smart board. The CEDAR area is envisioned as excellent for on-the-spot design review capability for any project during all phases of development. However, they pointed the need for improvement in processing times for making the group interaction process effective. Hartmann et al. (2003) illustrated an interactive workspace called IRoom created at the Center for Integrated Facility Engineering (CIFE) of the Stanford University in California. The IRoom provides three smart boards with projectors to represent a number of different views of the overall model simultaneously. The authors stated that this facility enables to structure, display and manipulate the various information used to design and implement a large construction project.

Jimenez and Mavris (2007) detailed the Collaborative Design Environment (CoDE) developed at the Aerospace Systems Design Laboratory (ASDL) of the Georgia Institute of Technology. This environment aims to build shared mental models by creating more engagement among participants, enhancing design team communication, and effectively interweaves both public and private spaces. The CoDE primarily constitutes the Sympodium (a flat panel computer screen to control the computer with the touch pen inclined on the main table), a Front-Projection SMART™ board on both side, and connection with the projector to switch effortlessly from the main table computer to any laptop. Jimenez and Mavris argued that the SMART™ board greatly improved the quality of the process in CAD modelling and visualization-intensive applications by reducing the level of difficulty in communication. The features identified for this merit are the large size of the work space, the ability to modify the design on that workspace with touch, the affordances provided by the virtual markers for markup, and the ability to capture and save the entire screen image with virtual marker sketches and author comments.

Duarte and Neto (2009) conducted studies to verify the hypothesis that "*users collaboratively decide task assignment based on the task characteristics and the different platform support*". The study concludes that the test participants agreed that text entering tasks should be performed by the laptop participant, while drawing tasks should be performed by the SMART board participant. Jang and

Schunn (2012) examined the pattern of tool use (computers, smart boards, notes, and prototypes) in 43 interdisciplinary engineering design teams enrolled in a full-semester product realization course. The study concluded that the successful teams were found to use a smart board and physical prototypes consistently more often throughout the design process. The unsuccessful teams used a computer, laptop, and paper notes more often. The reasons mentioned for this success for using smart board are that it supports collaborative work, promotes productive group discussion, and act as an extended memory system for accurate and flexible updating of shared mental models.

Stelian-Cornel and George (2013) illustrated the benefits of using SMART™ board to reduce time to make and to implement a modification on technical documentation. They argued that the project teams can understand better the changes and different point of views during the design process. The survey conducted by Wilson et al. (2014) observed that fifty-two (52%) of participants indicated that the meeting performance would improve using Interactive White Board technologies. Eris et al. (2014) evaluated a distributed sketching system (DSS) which constitutes of a digital camera and a vertically mounted glass plasma display at each site. Users draw directly on the displays with whiteboard markers, and delete marks with whiteboard erasers. The authors through the laboratory studies illustrate that the DSS enables the communication of mental models and construction of shared understanding during collaborative design sketching. Sangiorgi (2014) developed GAMBIT, which is a multi-platform sketching system with a distributed interface designed to be physically deployed around a table, with tablets and a projector. It is a web-based system operating through a browser. It used a set of three devices: Smartphone, Tablet and a large Tabletop (a horizontal smart board). The author noted that the system's speed was slower the smaller was the screen size (ranked from fastest to slowest as Tabletop, Tablet, Smartphone). The pilot study highlights that the big screen in front of users aids to discuss and refer to previously drawn ideas.

Although the benefits of using the Smart board in collaborative design are widely discussed, the quality of design sketches and outcomes generated with the Smart board is not studied in-detail. Also the process of integrating electronic sketches with CAD is not comprehensive. This research aims to find answers for these identified gaps.

3. Research Hypotheses and Methodology

The network of parameters studied in this paper to study integration of the Smart board with CAD software is illustrated in Figure 1. Except for 'quality of final design and sketches' parameters, all other parameters are collected straight forwardly from video protocols and captured documents. Completeness and understandability are the two parameters used to assess quality of final design. Completeness is defined as the degree to which requirements are satisfied in the final design selected. Understandability is defined as the degree to which the final design selected is clearly explicated. These two parameters are qualitatively assessed by the lead authors by providing a value in the scale of 1 (low) to 5 (high) for the final design generated in each experiment. The arrows in Figure 1 represent the influence of one parameter on another parameter.

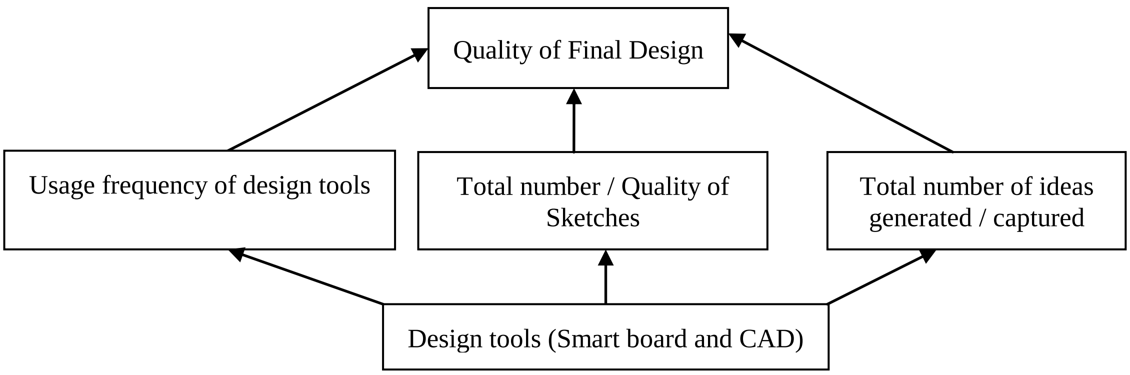

Figure 1. Influences and studied parameters

To assess the quality of sketches, a qualitative judgement schema proposed by McGown et al. (1998) is used. In this schema, each sketch is assessed for a measure of the information it communicated to the observer. The most simple of sketches (monochrome line drawing) is rated a 'One' and the most complex rated (3D form with proper annotations) a 'Five'. The importance of the Smart board along with the CAD tool is established through answering the following research questions:

- Q1. Which design tools (the Smart board and Rhino CAD software) are used to capture design ideas across the design stages?
- Q2. How many sketches are drawn using the Smart board and the CAD software across the design stages?
- Q3. How did the Smart board and CAD software complement each other in the design process?
- Q4. Does the tool usage frequency influence the overall quality of final design?

Table 1. Structure of the design experiments

	Original Design			Redesign		
Design problem	P1	P2	P3	P1	P2	P3
Design group (two designers)	G1	G2	G3	G4	G5	G6

All these research questions are framed for both the original and the redesign processes. To answer the research questions, a set of laboratory experiments were conducted with a pair of two designers working together to solve a design problem. Table 1 illustrates the structure of the design experiments conducted. We conducted three experiments each in the original and redesign processes. Variation due to design problems and design teams is incorporated by involving each group working on a different design problem. The three design problems used were to design: "a proper headphone adapt to user's dynamic activities", "secure laptop adequately while travelling", and "a moustache trimming device". Six design researchers, three 1st year master of design students, and three 2nd year master of design students participated in these experiments. Figure 2 illustrates the experimental set-up used to conduct the collaborative design sessions. We used two laptops and a SMART Board™ for all six experiments. This set-up provides both public and private spaces for the participants to work. The smart board is easy to use only by connecting the USB cable to the given laptop. A video projector was used to project the laptop screen to the Smart board. We have chosen Rhinoceros® CAD as the CAD software for these experiments. All the original design documents were given at the start of the redesign experiments. The participants were given training to use the given tools. Also, the participants solved a sample problem in the given set-up before starting the actual experiment. The time provided for each experiment was approximately one hour. Since the participants were aware of the capabilities of the tools, no specific instructions about the tool usage was provided. The research questions are answered from analysing captured video recordings and transcribed audio protocols.

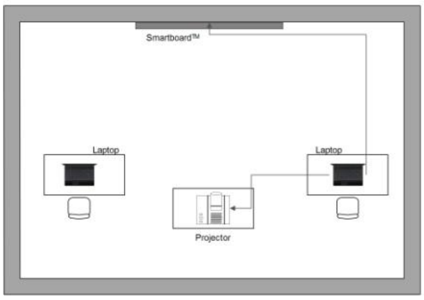

Figure 2. Experimental set-up of collaborative design

4. Results

The subsequent sub-sections answered the research questions from analyses of data from the six experiments.

4.1. Number of ideas captured with Smart board and Rhino CAD software

Table 2 tabulates the number of ideas captured in the Smart board and in the CAD software. The table clearly shows that the number of ideas captured in the Smart board is much higher than that in the CAD tool, both in the original and redesign problems, and in the preliminary and concept elaboration stages. The CAD tool is equivalently used at the detailing design concept stage. The issue observed from this analysis is that even with the usage of the Smart board along with the CAD software, the average percentage of uncaptured ideas (41%) is large. Compared to the original design stage (32.4%), the average percentage of uncaptured ideas in the redesign process (49.7%) is large. The uncaptured ideas are only communicated orally and discussed between the designers. Capturing the missed ideas could have influenced in generating more ideas in the redesign experiments. Currently the number of ideas created in the redesign phase is fewer than those in the original design process.

Table 2. Number of ideas captured with Smart board and Rhino CAD software

Experiment Tool		Number of Ideas Captured from								Total number of Ideas	Percentage of uncaptured ideas
		Smart board				Rhino CAD					
Problem / Design stages		PC	CE	DC	Total	PC	CE	DC	Total		
Original	P1	5	4	0	9	0	0	1	1	12	16.7
	P2	4	0	1	5	0	0	1	1	21	71.4
	P3	6	0	2	8	0	2	0	2	11	9.1
Redesign	P1	0	4	1	5	0	0	1	1	11	45.5
	P2	2	2	0	4	0	0	1	1	7	28.6
	P3	1	0	0	1	0	0	1	1	8	75.0

4.2. Number of sketches generated with Smart board and Rhino CAD software

Table 3 plots the number of sketches created in the Smart board and Rhino software along the design stages. The observations from Table 3 are listed below:

Table 3. Number of sketches and CAD models created in the Smart board and Rhino® CAD software in the design stages (in brackets – number of sketches x score value)

Experiment / Tool		Sketches in Smartbook						CAD model in Rhino CAD					
Problem / Stages		Req	PC	CE	DC	UP	Total	Req	PC	CE	DC	UP	Total
Original	P1	0	2 (2x2)	1 (1x1)	0		3	0	0	0	1 (1x5)		1
	P2	0	0	0	3 (2x2;1x1)		3	0	0	0	1 (1x4)		1
	P3	0	8 (7x1;1x4)	0	4 (3x4;1x5)		12	0	0	2 (2x3)	0		2
Redesign	P1	0	0	5 (3x2;2x1)	1 (1x2)	0	6	0	0	0	1 (1x5)	0	1
	P2	0	1 (1x2)	1 (1x3)	0	0	2	0	0	0	1 (1x4)	0	1
	P3	0	1 (1x3)	1 (1x3)	0	8 (6x1;2x4)	10	0	0	0	1 (1x3)	0	1

(Req-Requirement; PC-Preliminary concept; CE-Concept elaboration; DC-Detailing concept; UP-Understanding previous solutions (only for redesign))

1. No sketches are created at the requirement phase either with the CAD or the Smart board. But textual exploration of requirements was fully created and discussed using the Smart board rather than Rhino (Table 4), both in the original and redesign problems. Although the Smart board provides fluidity in writing textual elements, on average 30.3% of requirements generated are not captured.

Table 4. Number of requirements captured in the respective tools used

Experiment Tool		Number of Requirements (Req.) Captured		Total number of Req.	Percentage of Req. not captured
Problem / Requirement		Smart board	Rhino CAD		
Original	P1	9	0	12	25.0
	P2	2	0	10	80.0
	P3	7	0	7	0.0
Redesign	P1	11	0	11	0.0
	P2	5	0	11	54.5
	P3	7	0	9	22.2

2. The sketches generated at the preliminary concept stage are created solely using the Smart board. Rhino CAD software is primarily used in the detailed design stage.
3. From Table 2 and Table 3, the ratio of the number of sketches to the number of ideas created along the design stages are generated for both the tools (Table 5). The average ratio of the number of sketches to the number of ideas is almost one or less than one for both the tools. However, the Smart board has high fluidity of expression considering the average ratio of all the design stages (0.82) than Rhino CAD software (0.33).

Table 5 Average ratio of number of sketches to number of ideas created with the two tools

	Smart board			Rhino CAD		
	PC	CE	DC	PC	CE	DC
Original	1.1	1.3	0.3	0.0	0.3	0.7
Redesign	1.0	0.9	0.3	0.0	0.0	1.0

4.3. Complementation between Smart board and CAD software

Table 3 points out that only one out of six groups used the CAD tool to create sketches at the concept elaboration phase. The scores generated for sketches from the McGown et al.'s schema are provided in Table 3. The analysis of these scores reveals that the sketches drawn in the Smart board are within the scale of level 3. That is, the sketches are either simple/detailed monochrome line drawing with/without annotations, or detailed monochrome line drawing with some shading to suggest 3D form. None of the solo sketches drawn in Smart board emphasize 3D form or provide most realistic type of sketch which includes extensive shading and annotation. Although Rhino CAD is commonly used in detailing the finalised design, the CAD models generated have 3D forms with extensive annotations. But one of the groups (Original – Problem P3) did not use the CAD tool in the detail design stage. Rather they tried fusing the CAD drawing in the Smart board by transferring the concept elaborated CAD picture to the Smart board. Figure 4 portrays the drawing created by the designers. This fusing helps to generate realistic type of sketch in the Smart board. The intention of fusing CAD drawing in the support tool could be due to time pressure and/or CAD expertise level of designers. Using the Smart board along with the CAD software provides opportunity for the designers to express their intentions in the constraint situation. fussing

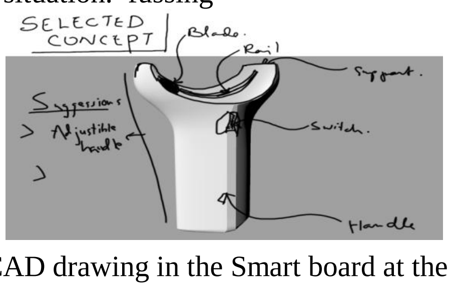

Figure 3. Fusing CAD drawing in the Smart board at the detail design stage

4.4 Influences of tool usage frequency and the overall quality of final design

The scores generated by assessing quality of the final designs through qualitative assessment are tabulated in Table 6. Also the frequency of tool usage with the each tool is provided.

Table 6. Qualitative assessment of quality of final design generated

		Quality of final design			Frequency of Tool Usage	
		Understandable	Completeness	Total score	Smart board	Rhino CAD
		Score: (1 - Low; 5 - High)				
Original	P1	5	5	10	1	1
	P2	4	2	6	2	2
	P3	3	3	6	5	4
Redesign	P1	5	5	10	2	3
	P2	4	4	8	3	4
	P3	2	2	4	12	9

Since the number of values within each set is less, a simple correlation study is conducted between the observed variables. Non-parametric Kendall's tau_b correlation factor is used because the variables of quality of final design are qualitative and ordinal. Table 7 summarizes the correlation observed within this study along with the significant level. There are strong negative correlations between the frequency of both tools usage and understandability of the final design. This result shows that if designers are moving between the given design tools more frequently than it is more likely that the final design outcome will degrade. The possible cause could be due to no interoperability between the given tools. The documents generated in one tool cannot be transferred to another without loss of information. The fusing approach used by one of the design groups (as illustrated in Figure 3) did not yield the best finished outcome.

Table 7. Notable correlation observed within this study along with the significant level

Variables	Correlation level	Correlation method
Understandable and frequency of Smart board usage	-0.889*	Kendall's tau_b correlation
Understandable and frequency of Rhino usage	-0.741*	
* p=0.05 (2-tailed) Significant level		

5. Discussion and Future work

Supporting sketches in electronic devices is an active research area due to the popularization of touch screen in mobiles, tablets, laptops and large screens. This requirement is emphasised by Cherubini et al. (2007) who mentioned that designers desire an intelligent whiteboard because it would not require hard mental operations while sketching during meetings and design sessions. The current study also established that designers would like to use the Smart board in all the design stages. But the CAD software is predominantly used in the detailed design stage. Although designers preferred the Smart board, the sketches drawn are either simple or detailed monochrome line drawing with/without annotations. Designers could not generate realistic 3D types of sketch in the Smart board. Also, the free-flowing production of sketches is not high where the average ratio of number of sketches to number of ideas is only one or less than one. This represents that there are constraints to establish complete freedom for expression and the ability to modify instantly with these tools combination. To emphasise this point, there are also high percentage of uncaptured requirements and ideas, as noted across all the experiments.

Another important finding from this study is that frequently switching and/or transferring design outcomes between the design tools leads to reduction of quality of final design outcome in the collaborative environments studied. One of the reasons for this reduction in quality is a designers' intention to add details to existing models, or deform and manipulate existing CAD design drawings in the Smart board and vice versa. Interoperability between the given tools (Rhino with Smart board) should be established to aid designers to express their intent freely without constraints. Some of the other features designers would like to have during designing are multi-touch smart board interaction (which is currently available) but should avoid recognising unwanted touches like palm touches while writing, reduce conflicts between mouse and Smart pen interactions (laptop and smart board interactions), increase in response time, eliminate deep press and write mode (which reduce the writing and sketch quality), and improve precision to choose particular feature while using CAD software in the Smart board.

These results show that electronic smart board sketching is still lagging behind classical sketching on paper. The current studies are extended to understand the interactions between the Smart board, tablet and paper like interactions. The future development towards paper-like displays and interactions to facilitate more natural media for explicit communication seems desirable.

References

Annamalai Vasantha, G.V., Chakrabarti, A., Rout, B. K., & Corney, J. (2014). Influences of design tools on the original and redesign processes. International Journal of Design Creativity and Innovation, 2(1), 20- 50.

Cherubini, M., Venolia, G., DeLine, R., & Ko, A.J. (2007). Let's go to the whiteboard: how and why software developers use drawings. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '07, 557.

Duarte, C., & Neto, A. (2009). Gesture Interaction in Cooperation Scenarios, L. Carri¸co, N. Baloian, and B. Fonseca (Eds.): CRIWG 2009, LNCS 5784, 190–205, Springer-Verlag, Berlin.

Hartmann, T., Fischer, M., Rank, E., Schreyer, M., & Neuberg, F. (2003). Integration of a Three Dimensional CAD Environment into an Interactive Workspace. CIFE Technical Report #146, Stanford University, USA.

Heer, J., & Bostock, M. (2010). Crowdsourcing graphical perception: using mechanical turk to assess visualization design. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 203-212). ACM.

Hernando, J., & Mavris, D. N. (2007). A Framework for Collaborative Design in Engineering Education. The 45th AIAA Aerospace Sciences Meeting and Exhibit.

Ibrahim, R., & Paulson, B. C. Jr. (2008). Discontinuity in organisations: Identifying business environments affecting efficiency of knowledge flows in PLM. International Journal of Product Lifecycle Management, 3, 21–36.

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

Jang, J., & Schunn, C. D. (2012). Physical Design Tools Support and Hinder Innovative Engineering Design. Journal of Mechanical Design, 134, 041001-1.

McGown, A., Green, G., & Rodgers, P.A. (1998). Visible ideas: information patterns of conceptual sketch activity. Design Studies, 19, 431–453.

Ozgur, E., Nikolas, M., & Badke-Schaub., P. (2014). A comparative analysis of multimodal communication during design sketching in co-located and distributed environments. Design Studies, 35, 559-592.

Robertson, B. F., & Radcliffe, D. F. (2009). Impact of CAD tools on creative problem solving in engineering design. Computer-Aided Design, 41, 136–146.

Rowe, S., Whitten, D., Cloyd, R., Coppens, C., & Rodriguez, P. (1998). An Example of Concurrent Engineering, AIAA, Paper 98-5278.

Sangiorgi, U. B. (2014). Electronic sketching on a multi-platform context: A pilot study with developers. Int. J.Human-ComputerStudies,72, 45–52.

SMART Technologies: Inspired Collaboration, http://smarttech.com/ 2014.

Stelian-Cornela, F., & Georgeb, D. (2013). Integrated Product Development using different Collaborative Tools in a PLM Multisite Platform. Applied Mechanics and Materials, 371, 867-871.

Wilson, M. D., Summers, M., Goris, T. V., Gordon, J.A. (2014). SMART R Boards: Implementing Technology for Innovation. 121st ASEE Annual Conference and Exposition, Indianapolis, IN.