A FEASIBILITY STUDY FOR DEVELOPING 3D SKETCHING CONCEPT IN VIRTUAL REALITY (VR) ENVIRONMENT

Farzad Pour Ramimian, Rahinah Ibrahim and Mohd Fakri Zaky Jaafar
Department of Architecture, Faculty of Design and Architecture,
Universiti Putra Malaysia, Malaysia

ABSTRACT

There is limited digital media available to encompass conceptual design which requires spontaneous and flexible design tools. The constraint is causing less digital integration during the architectural conceptual and engineering design stages. This paper presents the results of an ethnography research on understanding how design collaboration, design transactions and knowledge flow characteristics between studio masters and their students are supported by available technologies in a studio project in Malaysia. The study found three types of external representation modes used by designers: Full Manual, Mixed and Full Digital. The study revealed the inflexibility of traditional geometric modeling tools within intuitive ideations. On the other hand, it also observed the shortcomings of conventional manual sketching tools for articulating design ideas and translating tacit knowledge into explicit knowledge in complex design problems. Results from this study support further studies towards implementing 3D sketching in Virtual Reality (VR) environment to digitally integrate the conceptual architectural-engineering design process.

Keywords: Conceptual Design, 3D Visualisation, 3D Sketching, VR in Design

1. INTRODUCTION

With progressive globalisation and specialisation trends within the building industry, collaboration among design stakeholders in distant locations becomes crucial (Seng, Palaniappan and Yahaya, 2005; Wojtowicz, 1994). Today, *Computer Supported Collaborative Works* (CSCWs) (Wojtowicz, 1994) are no longer mere facilities, but an integral part of comprehensive architecture, engineering and construction (AEC) firms.
However, the type of non-collocated but synchronous communication is not sufficient to support knowledge flows in an operating environment that requires socialisation and internalisation (Ibrahim and Nissen, 2007) of verbatim responses combined with facial and physical reactions. Without conventional face-to-face protocols, the inefficient tacit knowledge movements tend to lead towards serious misunderstandings among design team members during the tacit-dominant design process (Griffith, Sawyer and Neale 2003; Ibrahim and Paulson, 2008). To address this problem and to support digitisation of the conceptual architectural design process, Moum (2006) proposes to use high-tech visualisation techniques and media. Moreover, Fruchter (1998) recommends that integration of design and construction process can better support collaboration among team members. She states that integration has major advantages in decreasing labor and material costs within current comprehensive production procedure models.

Indeed before discussing about feasibility of any process integration, a deep understanding of the particular process and its characteristics is needed. Therefore, we will first discuss the characteristics of the architectural design procedure as explained by other scholars. The design process at the cognitive level comprises many design activities: analysis-synthesis-evaluation (Lawson, 1997), imaging-presenting-testing (Zeisel, 1981) and seeing-moving-seeing (Schön and Wiggins, 1992). After synthesising their concepts, designers generate goals and objectives through the analysis. They evaluate generated semantics and goals and send them for further assessment and synthesis (Kim and Kim, 2007). Amhelm (1977) asserted that the visual form and function of architecture are physically and mentally entangled, and that discovering mental aspects of visual forms should involve architects' understanding of interactions between form and function. Lawson (1997) emphasises that there is no obvious difference between problem and solution, analysis, syntheses or assessment in the design process. The design is a concurrent learning process about the nature of the problem and the variety of the achievable solutions (Moum, 2006).

The design problem is multi-aspect and iterative indeed. A designer should understand what really constitutes the problem to distinguish hierarchical relationships, to join and to combine (Lawson, 1997). To finalise the discussions of integration, discussions regarding design support tools are also needed since the quality of a design process—at least in the novices' level—is related to the characteristics of the tools that are being used within the procedure (Pour Rahimian, Ibrahim and Baharudin, 2008). Cross (1999) believes that the thinking processes of the designer hinge around the relationship between internal mental processes and their external expression and representation in sketches. According to Craft and Cairns (2006), abstracted external representations would assist designers in three key aspects: *communication*, *creation* and *collaboration*. Cross (1999) believes on the dialogue or 'conversation' that goes on between internal and external representations and acknowledges Schön's (1983) idea that design is reflective. Therefore, the designer has to have some media, which enables half formed ideas to be expressed and to be reflected upon—to be considered, revised, developed, rejected and returned to.

The design integration suggested by Fruchter (1998) is yet to happen since heterogeneous design media are being used during different design stages—i.e., conventional analogue format of design ideation tools which are used within early conceptual design phases are yet to be replaced with an appropriate digital formats. This replacement is desired in order to help the conceptual design stages better fit into the remaining computerised engineering parts of the design process. This disintegration of stages during the entire design process is due to the limited efficiency of Computer Aided Design (CAD) software for intuitive sketching activities that designers still struggle to ensure the transfer of information from the conceptual architectural design to rational engineering parts (Kwon et al., 2005). Another reason is that majority of existing geometric modeling software entail a high degree of specialisation from the designers in order to achieve the final forms that they desire. However, not necessarily all designers can and need to reach this distinctive degree of skill (Levet, Granier and Schlick, 2006) hence leading to limitations to unreservedly capable of expressing ideas. Consequently, such constricted approach, in turn, hampers the capability of the design process and the collaboration that goes along with it (Kwon et al., 2005).

As mentioned above, a deep understanding of design process and the characteristics of currently used methodologies is needed to find a successful methodology for handling the conceptual design phase. Many researchers have conducted experiments in this area to evaluate different media during a short-term design activity in a laboratory condition (Bilda and Demirkan, 2003; Brown et al., 1995; Meniru, Rivard and Be´dard, 2003; Stones and Cassidy, 2007). To obtain better understanding about what really is happening to the designer when working with different types of media during conceptual design collaboration, we chose an ethnographic approach on a long-term and real design studio project.

This paper presents the results of that ethnography study. After it introduces the background problem and the selected design literature, it explains the ethnography methodology for data collection and analysis, and presents the resulting collaboration characteristics among designers during the conceptual design process. In conclusion, it discusses how the results could guide us in developing a 3D sketching prototype system using VR technology.

2. BACKGROUND PROBLEM

During conceptual design process, designers generate and develop design solutions by conducting diverse intellectual and physical tasks. Fish and Scrivener (1990) argue that the development of useful ideas and concepts can be facilitated or even hastened by the graphic form of used external representations. While variety of design tools are available nowadays, both designers and researchers still desire a new medium through which design development is better represented and more intuitive so that all design stockholders can obtain better understanding of design procedures. To realise what characteristics design tools should have, a deep understanding of the design process is needed.

A number of literature highlight sketching using pencils and papers as one of the most important abstract external representation methods. By the year 2000, its effectiveness—particularly within early conceptual design stages—was frequently appreciated (Cross, 1999; Fish and Scrivener, 1990; Goldschmidt, 1994; Kavakli, Scrivener and Ball, 1998; McGown, Green and Rodgers, 1998; Purcell and Gero, 1998; Rodgers, Green and McGown, 2000; Scrivener, Ball and Tseng, 2000). Schön and Wiggins (1992) highlighted the importance of freehand sketches as an indispensable medium for designers to make reflective dialogue with their own ideas. Suwa and Tversky (1997) concluded "sketches allow architects to *'read-off'* non-visual functional issues from visual features." They also argued that because of the rigidity of initial digital design tools, designers are still willing to freehand sketches for pure concept development. Their argument is supported by Lawson (1997) who ironically calls the CAD tool as Computer Aided Drafting rather than Computer Aided Design. Yet such gratitude to manual sketching aided design methodologies started fading with improvements to Computer Aided Design (CAD) tools, and their increasing utilisation in complex projects due to globalisation challenges. Due to distinctive shortcomings of manual sketching tools in visualization of complicated design alternatives, discussions about the need for digitalization of sketching were triggered particularly when scholars (such as Suwa, Gero, and Purcell 2006) hinted on the role of sketches as 'perceptual interface'. Here perceptual interface is defined as an aid for someone to discover the mental functional relations of design solution comprising the visual features. This has motivated Suwa and Tversky (1997) to propose the development of digital-sketching tools that provide the functionality of fortifying perception. They believe that if a digital sketching media can motivate designers to react to visual details in sketches and enable them to interpret what they are proposing, it would encourage designers who may elicit better usage of their sketches as 'perceptual interfaces'. Hence, they conclude that digital sketching can help particularly novice designers especially in improving their design interactivities.

With enhancements in hardware and software of CAD tools, early third millennium has witnessed the increasing tendency for using such tools in architectural design projects. Many scholars were impressed with excellent capabilities of CAD tools especially with their advanced photorealistic visualisation of projects (Madrazo, 1999; Marx, 2000). Madrazo (1999) advocates the idea that design should be done completely in a digital environment and without any role of conventional design methodologies. Yet, the question is whether current CAD tools are efficient enough to handle the conceptual design stages and replace the manual sketching which is in analogue format.

Nevertheless, doubts about the effectiveness of CAD current tools in handling early conceptual design stages started almost concurrently with these appreciations. Suwa et al. (1998) doubted the usability of such tools when they mentioned that although CAD media have had a huge impact on the effectiveness of design groups, there are still characteristics of designing which are exclusively related with freehand sketches. Kwon et al. (2005) attributed this lacking to the limitation of intuitive sketching capabilities of CAD software. Then, such tools are yet to replace current manual sketching media which are being used within conceptual architectural design stages. However, due to complexity of current design projects, most of the parts of building design which are called engineering design stages have already shifted to the use of digital media thoroughly. Hence, we note the potential stark differences between technical architectural and engineering drafting versus the intuitive conceptual design ideation by architects. Our observation supports Fruchter's (1998) earlier findings on the potential losses of tacit knowledge within transitions of interrupted design process. Therefore, to fill in the mentioned gap between precise manufacturing oriented design tools and the effortless intuitive idea creation media, designers desire some sketch-like media which are as the same format with the tools they would use during different parts of the design process. In order to fill the gap between these two types of design methodologies, we need to know both parties well. Therefore, we need to observe the designers' collaboration efforts using different types of design media activated during a studio design project.

Many researches in existing literature that experimentally compare the effectiveness between traditional sketching tools and digital media involve a short-term conceptual design activity conducted in a laboratory condition (Bilda and Demirkan, 2003; Brown et al., 1995; Meniru, Rivard and Be´dard, 2003; Stones and Cassidy, 2007). Due to difference in duration of such "Charrette" based design programs and what happens within actual design studios, our concern is whether the results obtained from such experiments can be generalised to all kinds of design process. Unlike prior studies, this study uses ethnography research methodology to study the design process in a real-time architectural design studio project. Here, we focused on the collaborative culture within the conceptual architectural design process and the support value of current external representation methods during the studio design process that utilise both conventional manual sketching methods and Computer Aided Design (CAD) methods. The following section explains the ethnography research methodology.

3. ETHNOGRAPHY RESEARCH METHODOLOGY

An ethnography research studies an intact cultural group in a natural setting and allocating prolonged period of time for primary observational data collection (Spradley, 1979; Creswell, 1998). In this study, we seek to study the collaborative behaviors between studio masters and students of a 2^{nd} year architectural design studio at a public university. The gatekeeper for the architectural design studio was the Studio Master. We limit the study to the understanding about the changes in collaborative patterns with changing design mediums by designers. The primary data collection took place during a ten-week period of a selected design project where the first author played the observer role during the entire data collection process. The level and outputs of the relevant design activities are commensurable to the conceptual phase of a real-life architectural design where sketching and building simulations happened. Our research goal is to understand the design characteristics and support values of current design methodologies. Our ethnographic research question is: **What are the supportive characteristics of different design methodologies to support design collaboration during conceptual architectural design phase?**

The design studio comprised of four design mentors and 38 students who are involved in the schematic design of a handicraft arcade in Terengganu, Malaysia. One of the design mentors is the gatekeeper. The study focused on the interactions between an expert (i.e., the mentor) and a novice (i.e., a second year architectural student). Collaborative behaviours and communications of designers with other designers were observed and recorded. During this 10-week period, 16 class sessions were held with each lasting 6-7 hours. Observations were recorded manually and on digital videotapes throughout the studio period. Each session was transcribed in text in its entirety (Pour Rahimian and Ibrahim, 2008). We obtained weekly affirmation from the gatekeeper regarding our observations on the previous week for validation. For additional validation, the ethnography study's results were compared to existing theories (see Section 5).

4. RESULTS AND ANALYSIS

In this section, we present our ethnography results and analysis in Spradley's (1980) Level Four descriptive reporting. The results and analysis are divided into two parts. The first part reports the quality of the architectural design process and its external representations while the second part reports the design output quality.

4.1 Quality of Architectural Design Process and Its External Representations

In this section, we present the changes in the quality of design process that occur with changes of design tools. We had earlier divided the communication activities during the design process into two categories: 1) individual design communications, i.e. communication of designer with his design situation; 2) group design communications, i.e. communication of designer with others (Figure 1).

Individual communications happened when students tried to: a) adapt the existing form of some readymade design solutions published in magazines and books to current design problem requirements; b) start recalling his/her visual literature to create some preliminary forms and then evolve them into more complicated masses while considering aesthetical rules and other relative polices, e.g., logical circulation and structural considerations; c) begin simply with bubble diagramming that inspire meaning to diagrams during iterative design lifecycle process; and d) recall some gestalts from their mind for weighing site factors (e.g., culture, climate, people's lifestyle, etc) and adapt function to the form during design.

(a) *(b)*

Figure 1: (a) Individual and (b) group activities of students.

We note during our observations that regardless of the interaction mode used for individual design communication, the iterative attribute of design was more obvious during the early conceptual design stage. In several cases, we documented an entire change in a design solution when designers changed only a part of the design alternative. Consequently, the students had to reconsider their previous design decisions as tradeoffs to the new design change. Fuzziness, coarse structures and elements, and a trial-and-error process characterised this early stage. Moreover, due to the high chance of correcting errors during this stage, we observed the maximum use of low-expenditure sketches and physical models.

Despite the fact that each method of individual design communication requires its own particular procedure for enrichment of design alternatives, the role of external representation in inspiring and amplifying design semantics is obvious during the design process. The study was able to observe several instances when students would stop their thinking process at a distinctive stage because of their inability to manipulate their design solution using a particular design tool. The following two subsections explain students' challenges with manual sketching and computer aided design tools.

4.1.1 Benefits and Challenges of Conventional Manual Sketching during Conceptual Architectural Design Process

Our observations indicated that in spite of their flexibility in intuitive ideation capabilities, there were incidences where students encountered serious problems when using manual sketching tools as the only design support system. Mentioned here are some of those challenges:
An important observation for all three styles of individual design communication indicated that students were continually shifting their attention from macro level to micro level and vice versa. This design activity would require a medium with a high degree of capability for visualising design alternatives. Since the conventional manual sketching tools—at least at the novice level—did not have these capabilities, these students faced numerous problems in frequently changing the scale of representation. That was the time when students would rather use CAD tools to aid them in manipulating their design solutions.

The other category of our observations was collaboration between students and masters during walkthrough sessions. According to Wikipedia (Wikipedia, 2008), a walkthrough is a term describing the consideration of a process at an abstract level. A walkthrough is a metaphor used in design when other design stakeholders review a designer' goal space. Our observations found a tendency by both student and master to imagine the design alternative in mind while they were talking about it. Although they had this tendency, they never managed to have a seamless walkthrough process. We observed that due to inherent characteristics of conventional design tools, designers had some difficulties in communicating their design intentions when they were involved in complicated design tasks. We observed many misunderstandings that happened during conventional manual design process, in particularly when students were not very fluent in sketching and they had major problems describing their design ideas.

Here is an account of an event observed during one of our observations regarding the aforementioned misunderstanding, i.e., miscommunication in design intention. It involved a student and a mentor who was using manual sketching media to design a proper structural system. The mentor showed the order of columns placed by the student and said: *"These are untidy. You should rearrange them in a better order."* Then he tried to evaluate the load carrying system of the building. Yet, the information exposed on the paper was insufficient. At this point, both subjects put the conventional drawings aside and used other media to improve information transactions. To simulate the relationship of two perpendicular spatial elements, the mentor vertically put his pencil on the table and horizontally attached his fingers to it. Then he asked the student, *"Is this the design that you meant?"* The student shook her head slightly and said, *"No."* After that she tried to explain the system that was in her mind. First, she drew a small section on the corner of her drawing paper and said: *"Is this clear?"* Nevertheless, it was not clear enough for the mentor. Suddenly, the student referred to her physical model to help her clarify her design idea. She used the physical model to explain the mechanism of its load carrying system. When viewing the physical model, both changed their physical positions (from standing to sitting) and also the orientation of the model (by turning it) frequently in order to see the model from various viewpoints. These behaviors reflect the concept of zooming and rotating facilities in modeling software. Eventually they removed some parts of the model to better see the inner parts (as managing the layers in CAD). Somehow, these destructive interferences could not be undone later.

4.1.2 Benefits and Challenges of Computer Aided Design (CAD) Tools during the Conceptual Architectural Design Process

Here we explain using another sample of group communication which is digital visualisation method. We observed that fragile models and concrete sizes of conventional design tools caused much inconvenience for our mentors and students when shifting views from macro to micro and vice versa. This problem was partially solved after students used different CAD tools when modeling their design alternatives. We had some cases where the utilisation of CAD tools enabled the student to look at the virtual model from different distance or desired viewpoint. Moreover, undoing undesired changes was much easier in comparison to those using conventional systems. CAD tools further motivated and encouraged the designer since he/she could easily reverse the undesirable situation. These incidents occurred quite frequently during our observation. Additionally, we observed students who used digital tools were more confident in making design alternatives since they were could easily undo the undesirable changes.

However, we also observed that after struggling for a long time to solve a simple design problem, the student finally gave up and replaced the CAD medium with the traditional one due to the deficiencies of those I/O devices of the computer. Nonetheless, our observations of students' final presentation revealed that using CAD tools during conceptual design phase would curtail students' creativity and ingenuity due to so many shortcomings in freely expressing design ideas freely.

4.2 Design Output Quality

Overall, the study noted three dominant types of sketching used by the students and their studio mentors: *Full Manual*; *Mixed* and *Full Digital*. The Full Manual Mode uses only traditional sketching tools and abstract modeling methods while the Full Digital Mode starts design in CAD environment and continues until the design is finalized with it. For the Mixed Mode, the design starts with using traditional methods, but later continues the process utilising CAD modeling tools.

We noticed that using manual sketching process would allow a designer the opportunity to trade off between accuracy and clarity, e.g., designer used high accuracy for drawing the building while no unnecessary precision is spent to replacement of the trees (Figure 2). We had many cases during manual sketching walkthrough stages that designers were able to use different scales of drawings to avoid unnecessary details to make easier understanding. On the other hand, digital method designers had to use the same degree of accuracy for all parts of the digital model. Therefore, designers using manual method in projects were able to convey their design ideas more directly compared to the others; i.e., intentions of designers in such drawings became clearer. Within these projects, relationships of site plan elements were smoother, e.g., the way in which the wings of the building cross the landscape and the lake in Figure 2. Moreover, despite having a lower accuracy for such manual works, their presentations seem more emotive, and capable of carrying stronger concepts of design (Figure 3). However, in a fully manual process, the works were almost raw and usually stopped at a distinctive level (Figure 4). For example, due to weakness in external representations during design process and in spite of good initiated design concept, some design requirements did not match with the initial idea in the mind.

On the other hand, computer made perspectives were more elaborated, involved more details, were more realistic, and included nicer interiors, e.g., details of lighting, paving, design and color of furniture, acoustic considerations of the ceiling system (Figure 5. Yet in most of those cases, we witnessed some inconsistencies among different spaces and they lacked a sense unity regarding the spaces (e.g., even though both belonged to the same building, the disparities in perspectives shown in Figure 6 were in contrast with the rhythmic facades design exposed in Figure 7. During the digital design process, the designer saw the alternative in perspective rather than plans and elevations. Usually, these perspectives in such cases were more breathtaking compared to manually designed projects. On the contrary, due to lack of holistic consideration of the building and thoroughly being immersed in the perspectives, silhouettes in such cases were boring and lacked artistic outlooks (Figure 7).

Nevertheless, the most amazing spatial volumes belong to computer-aided designs whilst the nicest conceptual spatial senses are from manual design attempts. While most computer-generated or computer-aided works have similar characters, manual exploits are mostly unique. To conclude, the most successful cases were those designed manually completely but visualised digitally (Figure 8) where in such cases the designers utilized the capabilities of each method to compensate the shortcomings of the other. In other words, neither traditional sketching method nor conventional CAD software is the perfect media to be used during conceptual architectural design process. Table 1 summarizes the challenges and benefit of both methods.

Table 1: Summary of Challenges and Benefits of Each Visualisation Method during Conceptual Architectural Design Phase

	Benefits	Challenges
Current Manual Sketching tools	• Flexibility in ideation due to tangible interface; • Ease of use; • Ease of learning; • Ease of changing reforming the design alternative; • Ability for using different scales of drawing and trading of between accuracy and clearness; and • Maintaining design idea during design process providing the ability to see all documents together and to compare.	• Lower capability for shifting from micro to macro level and vice versa; • More tacit knowledge flow walkthrough; • Lower details of visualisation; • Fragile models and documents for editing or reviewing; • Failing to add and control more details into design alternative due to week level of visualisation; and • Difficulty in transition of the format when being used in the other design stages.
Current CAD tools	• Easier documentation; • Capability for zooming and pan for easier walkthrough; • Capability for temporally omitting an object or group of objects; • Capability for undoing undesired changes; and • More detailed, realistic, and elaborated perspectives due to high capability of visualisation.	• Difficulty of obtaining ability to use; • Arduousness of I/O devices which interrupt creativity of the designer; and • Losing consistency of spaces due to lack of ability to control ubiquitous design idea in an artistic way.

Figure 2: Presentation of site plan completed fully manual.

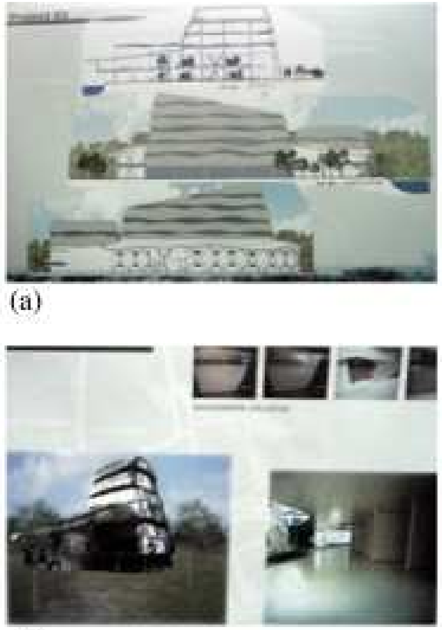
Figure 3: Presentation of a perspective using Full Manual Mode.

Figure 4: Presentation of a project with no aid of computer.

Figure 5: A computer generated interior space.

Figure 6: Ambiguous perspectives in fully digital design.

Figure 7: Boring silhouettes of fully digital design alternatives.



(a)

(b)

Figure 8a and 8b: A successful project done using multiple digital and manual representation techniques during design process

5. DISCUSSION/RECOMMENDATIONS FOR FUTURE STUDIES

We conducted an ethnography research to understand collaborative behaviors of designers in order to understand the role played by different types of external representations during the conceptual architectural design phase. Our observations support Kim and Kim's (2007) study that the early conceptual design stage is the phase where solutions, problems and inspirations flourish. Therefore, the entire design process is affected by quality of this stage. Indeed, searching for form and shape ("gestalt") is the principal goal of the designer during this phase (Craft and Cairns, 2006).

Particularly during walkthrough sessions, designers use design support tools not only as mere presentation media but for imagination of design alternative in mind while they were talking about it—same like what Schön (1983) argues saying that every designer operates in a virtual world, an imitated simulation of the real world in practice. Indeed, we obviously observed the role of external representations not only as memory aids, but also as facilitator and constrain for inference, for the problem-solving, and as stage of understanding during idea generation process (Suwa and Tversky, 1997). Now we empirically experienced Suwa et al.'s (1998) idea that designers can benefit from abstract external representations (i.e. sketches) particularly while they are in the early conceptual design stages. Now we support Pour Rahimian, Ibrahim and Baharudin's (2008) idea that the characteristics of design process and its external representations are strongly affected by the tools that designers use embodying their designed concepts.

During our observations, we observed three types of external representation modes used by designers: *Full Manual*, *Mixed*, and *Full Digital*. The study reveals that designers have major problems working with current design tools, no matter whether it is analogue or digital. We noticed the inflexibility of traditional geometric modeling tools within intuitive ideations on one hand and on the other hand facing with complex design problems, we observed the shortcomings of conventional manual sketching tools for articulating design ideas and translating tacit knowledge into explicit knowledge. Such shortcomings of current design support tools are increasing our tendency for some substitute modeling techniques that can be called as 3D sketching. To be successful design medium, this alternative tool is expected to supports all intuitive idea expression, the precise manufacturing oriented modeling, and effortless design walkthrough.

Using the sketching metaphor, Levet et al. (2006), propose to use of some design methodologies in which designers can swiftly produce a 3D prototype to exemplify the 3D object they have in mind. This is considered by Kwon et al. (2005) to improve computer performance contribute for the speeding up of the incorporation of the conceptual phase into the rest of the design stages, i.e. applying the digital format rather than such analogue conventional tools that are used. Based on our observations, current digital sketching tools are not very successful within conceptual design phase. We have many examples that students struggled with handling such software to generate their design idea. The main problem of students with using currently available digital sketching tools is with their improper I/O systems. To address this problem, we support Fiorentino et al.'s (2002) idea to use Virtual Reality (VR) methods rather than traditional 2D devices (mouse, keyboard, and monitor) for specifically facilitating sketching directly in a 3D space in an enhanced intuitive style. Since, VR offers a better insight of 3D with providing direct drawing and editing through 3D interaction mediums to articulate the design concepts (Kwon et al. 2005). Consequently, VR can offer the ideal interface for free artistic visualisation and linking creative experimentation and accurate manufacturing-oriented modeling (Fiorentino et al. 2002).

We posit that we may be able to develop a 3D sketching prototype with the available 3D modeling applications that are based on the VR technologies. We propose to use of digital sketching systems which could develop 3D models on the computer by drawing directly in 3D space in a natural and quick manner (Kwon et al. 2005). Another possibility is creating surfaces by moving a hand, wearing on a special glove (data glove) through space in a semi-immersive 3D display and interaction environment (Schkolne, Pruett, and Schroder 2001). The other tool is wearing a head-mounted display (HMD) with a head tracking system which can support effortless 360 degree fully immersion in the design environment. Finally, we can use haptic technologies to facilitate force feedback and vibration senses to fortify the tangible interfaces, which are strongly admired by Kim and Maher (2008).

The main objective of proposing 3D sketching in VR is allowing the transition of analogue design process to digital procedure in order to improve the integration of the entire design process. We propose future studies to include how transdisciplinary teamwork would use 3D sketching methodology within a building design process. We expect that the results of such research could be successful for enabling professionals to document and amplify design semantics throughout a project development lifecycle phases. This study supports Ibrahim's (2007) recommendation for advancing methodologies and technologies in the design phase that leads towards 4D construction implementation while, also developing a new generation of architects who are able to work collaboratively in geographically dispersed locations.

6. ACKNOWLEDGMENTS

We acknowledge that this research is a part of doctoral study by the first author at Universiti Putra Malaysia (UPM), and partly sponsored by UPM's Graduate Research Fellowship (GRF). We acknowledge contributions of the mentors and second year students in the ARC 3003 Architectural Design Studio Semester 2 2007/2008 at the Faculty of Design and Architecture, UPM. We also acknowledge the contributions of Associate Prof. Dr. Mohd Saleh B. Hj Jaafar, Associate Prof. Dr. Rahmita Wirza Binti O. K. Rahmat, Dr. Muhamad Taufik B. Abdullah and Dr. Mohd Fakri Zaky Jaafar during this study.

7. REFERENCES

Amhelm, R. (1977). *The dynamics of architectural forum*. Berkeley, University of California Press.

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

Brown, F.E., G.S. Cooper, S. Ford, G. Aouad, P. Brandon, T. Child, J. A. Kirkham, R. Oxman, and B. Young (1995). An integrated approach to CAD: Modelling concepts in building design and construction, *Design Studies* 16 (3): 327-347.

Craft, B. and P. Cairns (2006). Work interaction design: Designing for human work. *Proceeding of the First International Federation for Information (IFIP TC 13.6 WG) conference: Designing for human work* organized by Federation for Information Processing in Madeira on February 13-15.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, Sage Publications, Inc.

Cross, N. (1999). Natural intelligence in design, *Design Studies* 20(1):25-39.

Fiorentino, M., R. De Amicis, A. Stork and G. Monno (2002). Surface design in virtual reality as industrial application. *Proceedings of International Design Conference–Design* organized by the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb in Dubrovnik, Croatia on May 14 – 17: 477-482.

Fish, J. and S. Scrivener (1990). Amplifying the mind's eye: Sketching and visual cognition, *Leonardo* 4: 117–226.

Fruchter, R. (1998). Internet-based web mediated collaborative design and learning environment, in artificial intelligence in structural engineering. In *Lecture notes in artificial intelligence,* Berlin, Springer-Verlag: 133-145.

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

Griffith, T.L., J. E. Sawyer, and M.A. Neale (2003). Virtualness and knowledge in teams: Managing the love triangle of organisations, individuals and information technology, *MIS Quarterly* 27 (2): 265-287.

Ibrahim, R., and B.C. Paulson, Jr. (2008). Discontinuity in organisations: Identifying business environments affecting efficiency of knowledge flows in PLM, *Intl. J. of Product Lifecycle Management*, 3 (1): 21-36.

Ibrahim, R. (2007). Mitigating environmental characteristics with integrated design and automated construction approaches for AQH development, *Alam Cipta, International Journal on Sustainable Tropical Design and Research* 2 (1): 11-18.

Ibrahim, R. and M. Nissen (2007). Discontinuity in organisations: Developing a knowledge-based organisational performance model for discontinuous membership, *Intl. Journal on Knowledge Management* 3 (1): 10-28.

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

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.

Kim, S. A. and Y. S. Kim. 2007. Design process visualisation and review system with architectural concept design ontology. *Proceedings of the International Conference on Engineering Design (ICED'07)* organized by Cite des Sciences et de L'Industrie in Paris, France on 28-31 August 2007.

Kwon, J., H. Choi, J. Lee and Y. Chai (2005). Free-hand stroke based Nurbs surface for sketching and deforming 3D contents. In *Proceedings of the Advanced Multimedia Information Processing- PCM 2005 Part I,* Lecture Notes in Computer Science (LNCS) Lecture 3767: 315 – 326.

Lawson, B. (1997). *How designers think – the design process demystified*. Oxford, Architectural Press.

Levet, F., X. Granier and C. Schlick (2006). 3D sketching with profile curves. In *Proceedings of the Advanced Multimedia Information Processing-PCM 2005 Part I,* Lecture Notes in Computer Science (LNCS) 4073: 114–125.

Madrazo, L. (1999). Types and instances: A paradigm for teaching design with computers, *Design Studies* 20 (2): 177-193.

Marx, J. (2000). A proposal for alternative methods for teaching digital design, *Automation in Construction* 9 (1): 19-35.

McGown, A., G. Green, and P.A. Rodgers (1998). Visible ideas: Information patterns of conceptual sketch activity, *Design Studies* 19 (4): 431-453.

Meniru, K., H. Rivard, and C. Be´dard (2003). Specifications for computer-aided conceptual building design, *Design Studies* 23 (1): 51–71.

Moum, A. (2006). A framework for exploring the ICT impact on the architectural design process, *Journal of Information Technology in Construction* 11 (Special Issue: The Effects of CAD on Building Form and Design Quality): 409-425.

Pour Rahimian, F. and R. Ibrahim (2008). Design Studio Ethnography Report, Environmental Design Integration Technical Report EDI/TR1, Faculty of Design and Architecture, Universiti Putra Malaysia.

Pour Rahimian, F., R. Ibrahim, and M. N. Baharudin (2008). Using IT/ICT as a new medium toward implementation of interactive architectural communication cultures. Proceedings of the *International Symposium on Information Technology* organised by IEEE in Kuala Lumpur, Malaysia on 26-28 August: 1530-1540.

Purcell, A.T. and J.S. Gero (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.

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

Schkolne, S., M. Pruett and P. Schroder (2001). Creating organic 3D shapes with the hand and tangible tools. *Proceedings of* Special Interest Group on Computer-Human Interaction *SIGCHI 2001* organized by the Association for Computing Machinery in Seattle, Washington, USA on 31 March – 5 April.

Schön, D. (1983). *The reflective practitioner: How professionals think in action,* London, Temple Smith.

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

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

Seng, W.K., S. Palaniappan and N.A. Yahaya (2005). A framework for collaborative graphical based design environments. *Proceedings of the 16th International Workshop on Database and Expert Systems Applications 2005* organized by IEEE Computer Society in Copenhagen, Denmark on 22-26 August.

Spradley, J.P. (1980). *Participant observation,* New York, Holt, Rinehart, and Winston.

Spradley, J.P. (1979). *The ethnographic interview,* Belmont, Wadsworth Group/ Thomas Learning.

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

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

Suwa, M., T. Purcell, and J. Gero (1998). Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies* 19 (4): 455–483.

Suwa, M., J. Gero and T. Purcell. 2006. Analysis of cognitive processes of a designer as the foundation for support tools. Available at http://cs.gmu.edu/~jgero//publications/1998/98Suwa_Gero_PurcellAID98.pdf retrieved on 23 December 2008.

Wikipedia (2008). Available on http://en.wikipedia.org/wiki/Walkthrough, retrieved on November 11, 2008.

Wojtowicz, J. (1994). *Virtual design studio*, Hong Kong, Hong Kong University Press.

Zeisel, J. (1981). *Inquiry by design: Tools for environment-behavior research,* Cambridge, University Press.