UNIVERSITI PUTRA MALAYSIA

COGNITIVE TRANSFORMATION MEDIATED BY DIGITAL 3D SKETCHING DURING CONCEPTUAL ARCHITECTURAL DESIGN PROCESS

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By

FARZAD POUR RAHIMIAN LEILABADI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

August 2009

DEDICATION

To my wife, Mina

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chair: Associate Professor Dr. Rahinah Bt. Ibrahim, PhD

Faculty: Design and Architecture

To optimize the level of cognition and collaboration during conceptual architectural design phase, novice designers need to employ more flexible and intuitive digital media. This thesis studied the feasibility of using VR 3D sketching interface in order to replace current non-intuitive Computer Aided Design (CAD) tools. For this purpose a sequential mixed method research methodology including a qualitative case study research and a cognitive-based quantitative protocol analysis experiment was conducted.

Foremost, it was pertinent to understand how novice designers make intuitive decisions. Hence, a case study research comprising of ethnography for data collection and artifact and protocol analysis for data analysis was employed. The purpose was to understand knowledge flow characteristics among mentors and apprentices in real-life architectural conception in studio projects. The ethnography study documented the failure of conventional sketching methods in articulating complicated design ideas. Whereas, it

found that current conventional CAD tools do hinder novice designers' creativity due to their limitation in intuitive ideation. Moreover, the subsequent artifact analysis affirmed established constructs about advantages and disadvantages of each medium in providing *"solution quality"* and also *"certainty about correctness of solution"*.

The case study's findings then became the theoretical foundations for the development of a VR 3D sketching interface for enhancing novice designers' cognition and collaboration during the conceptual design process. This phase of study evaluated the designers' spatial cognition at four different cognitive levels: *"physical-actions"*, *"perceptual-actions"*, *"functional-actions"*, and *"conceptual-actions"*. It also evaluated the designers' spatial cognition in two different collaborative levels: *"cognitive synchronizations"* and *"gestures"*. The results and confirmed hypotheses showed that compared to traditional design interfaces, the utilized VR-based simple and tangible 3D sketching interface improved novice designers' cognitive and collaborative design activities during conceptual architectural phase.

In summary the thesis has evaluated inherent characteristics of the conceptual architectural design process and documented influences of current external representation tools on designers' cognition and collaboration. It has developed the necessary theoretical foundations for cognitive and collaborative aspects of implementing VR 3D sketching interface for future implementation. Results of this thesis are limited to implementation of VR 3D sketching interface to improve cognition and collaboration during conceptual architectural design process at the novice level.

In conclusion, this thesis contributes towards transforming conceptual architectural design phase from analogue to digital by proposing a new VR design interface. The author claims that this transformation can fill in the existing gap between analogue conceptual architectural design process and the remaining digital engineering parts of building design process hence enhancing the streamlining of digital design process. Finally, the author claims that the identification and documentation data on designers' cognitive and collaborative conceptual design behaviors in the Malaysian context can be used as reference in future design studies. It is envisioned that the findings of this study can help the development of cutting-edge information technologies for design or education in the architectural field. Moreover, they will guide in the creation of future professional training programs to enhance capacity and capability of multidisciplinary professionals in using digital interfaces due to increasing global practice.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

BANTUAN LAKARAN DIGITAL 3D DALAM TRANSFORMASI KOGNITIF SEMASA PROSES MEREKA BENTUK KONSEP SENI BINA

Oleh

FARZAD POUR RAHIMIAN LEILABADI

Ogos 2009

Pengerusi: Prof. Madya Dr. Rahinah Bt Ibrahim, PhD

Fakulti: Rekabentuk dan Senibina

Bagi mencapai tahap optimum pemahaman dan kolaborasi semasa fasa mereka bentuk konsep seni bina, pereka baharu perlu mengaplikasikan media digital yang lebih fleksibel dan intuitif. Tesis ini mengkaji kemungkinan penggunaan layar lakaran 3-dimensi dalam konteks alam maya bagi menggantikan aplikasi reka bentuk berbantuan komputer (*CAD*). Untuk tujuan ini, sebuah metodologi kajian campuran berturutan diguna pakai yang melibatkan kajian kes kualitatif dan analisis protokol kuantitatif berasaskan pemahaman telah dijalankan.

Terdahulu, adalah penting bagi memahami bagaimana pereka baharu membuat penilaian intuitif. Maka satu kajian kes yang berpandukan etnografi bagi pengumpulan data serta artifak dan analisis protokol untuk penganalisan data telah pun dijalankan. Ini adalah

bertujuan untuk memahami ciri-ciri aliran ilmu di kalangan mentor dan pereka baharu di dalam situasi sebenar ketika mereka bentuk konsep seni bina dalam projek studio. Kajian etnografi mendokumentasikan kegagalan teknik lakaran konvensional dalam merealisasikan ide-ide reka bentuk yang rumit. Dalam masa yang sama, ia mendapati aplikasi CAD konvensional masa kini menyekat kreativiti pereka baharu kerana kelemahan dalam penghasilan ide intuitif. Bahkan, analisis artifak berikutnya memperkukuhkan unjuran asas mengenai kebaikan dan kekurangan setiap media dalam menghasilkan "*kesimpulan berkualiti*" dan juga "*kepastian mengenai ketepatan penyelesaian*".

Hasil kajian kes seterusnya menjadi asas teori bagi pembangunan layar lakaran maya 3-dimensi bagi menambah baik pemahaman dan kolaborasi pereka baharu semasa proses reka bentuk konsep seni bina. Fasa kajian ini menilai pemahaman ruang pereka pada empat peringkat kognitif yang berlainan : *"tindakan fizikal"*, *"tindakan perseptual"*, *"tindakan berfungsi"* dan *"tindakan konseptual"*. Ia juga menilai pemahaman ruang pereka dari dua peringkat kolaborasi berlainan : "*penyelarasan kognitif*" dan "isyarat". Hasil keputusan dan kepastian hipotesis yang dibandingkan kepada layar reka bentuk tradisional mendapati penggunaan layar lakaran 3-dimensi berasaskan alam maya mempertingkatkan pemahaman dan kolaborasi pereka baharu dalam aktiviti reka bentuk semasa fasa konsep seni bina.

Sebagai rumusan tesis ini telah menilai ciri-ciri penting proses mereka bentuk konsep seni bina dan telah mendokumentasi pengaruh aplikasi alatan representasi luaran semasa terhadap pemahaman dan kolaborasi pereka. Ia telah menghasilkan asas teori yang

diperlukan untuk aspek pemahaman dan kolaborasi bagi menjalankan lakaran layar maya 3-dimensi untuk diimplementasikan pada masa hadapan. Keputusan tesis ini terhad kepada penggunaan lakaran layar maya 3-dimensi untuk mempertingkatkan pemahaman dan kolaborasi semasa proses mereka bentuk konsep seni bina di peringkat pereka baharu.

Kesimpulannya, tesis ini mebantu ke arah transformasi fasa rekabentuk konseptual senibina daripada analog ke digital dengan cadangan layar rekabentuk maya yang baru. Penulis mendakwa transformasi ini boleh mengisi kekosongan semasa diantara proses rekabentuk konseptual senibina analog dan juga baki bahagian digital kejuruteraan pembinaan seterusnya menambah baik kelancaran proses rekabentuk digital. Akhir sekali, penulis menuntut data dan dokumentasi mengenai tindak balas pemahaman dan kerjasama perekabentuk di dalam konteks Malaysia boleh diguna pakai sebagai panduan untuk kajian rekabentuk pada masa hadapan. Adalah diharapkan penemuan hasil kajian ini dapat menbantu penghasilan teknologi maklumat tersohor bagi rekabentuk dan pendidikan dalam bidang senibina. Lebih-lebih lagi, penemuan ini dapat membantu menghasilkan program latihan professional pada masa hadapan untuk meningkatkan keupayaan dan kebolehan pelbagai jurusan professional dalam mengunakan layar digital selaras dengan peningkatan penggunaan global.

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APPROVAL

I certify that and Examination Committee has met on date of viva to conduct the final examination of Farzad Pour Rahimian Leilabadi on his PhD thesis entitled "COGNITIVE TRANSFORMATION MEDIATED BY DIGITAL 3D SKETCHING DURING CONCEPTUAL ARCHITECTURAL DESIGN PROCESS" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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Date: **16 November 2009**

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institution.

FARZAD POUR RAHIMIAN LEILABADI

Date:

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LIST OF ABBREVIATIONS

VR	Virtual Reality
VE	Virtual Environment
CAD	Computer Aided Design
3D	Three-Dimensional
AEC	Architecture/Engineering/Construction
P-actions	Physical-actions
Pe-actions	Perceptual-actions
F-actions	Functional-actions
C-actions	Conceptual-actions
FC-actions	Functional and conceptual actions
S-inventions	Situative-inventions
CS-actions	Cognitive Synchronization actions
G-actions	Gesture-actions
Sub-RQ	Sub-research question
IT	Information Technology
ICT	Information and Communication technologies
I/O	Input/output
CDP	Collaborative Design Process
VRM	Virtual Meeting Room
CVE	Collaborative Virtual Environment
GUI	Graphical User Interface
TUI	Tangible User Interface

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the issues and motivations for this research followed by the research questions, aim, objectives, and research assumptions. It also outlines the employed mixed qualitative and quantitative research approach which includes case study and protocol analysis methodologies. The chapter also explains the components of each research methodology as well as their achievements and results. While the final sections of the chapter are dedicated to explanation of scope, outcomes, and the significance of the conducted research, it concludes with outlining the structure of the thesis.

1.2 Statement of issues

Quality of design strongly affects quality of buildings that we live in (Moum 2006). Design is an exclusive human activity and a critical aspect of many modern industries. Lawson (1997) acknowledges design as a multi-aspect, iterative and also complicated process. Among all design stages, the early phases of design process that the author will turn to are drastically affected by the quality of communications among team members. This study categorized the design communications into two groups: 1) between a designer and his or her design situation when trying to solve the design problem and 2)

between different designers during design collaboration. It is proposed to call the quality of such communications and the ways that the designers use to communicate as *"Collaborative Culture"*. Nowadays, communication culture of design is changing drastically. To better control the changes design researchers need to really understand the reason why these changes happen. The author would like to discuss two most important change reasons and the impact quality of these changes: *IT/ICT* and *Globalization*.

Undoubtedly the commencement of IT/ICT age is one influencing factor which causes some major changes in design process. Lawson (1997) posits that communication culture within every society depends on the tools that people use for their transactions. Today, we are witnessing the revolutions made by globalization in many societies. The culture and the way people interact are strongly affected by their needs and communication tools. In this instance, Cera et al (2002) posit that IT/ICT has revolutionized product design in the Architecture-Engineering-Construction (AEC) industries, in addition to other areas where geometric computation and visualization have proven essential. Recognizing IT/ICT as the most effective tool which influence the world's interaction culture in 21st century, Friedman (2005) acknowledges Cera et al's (2002) idea. Finally, Moum (2006) argues for this fact that participants within building design process encounter IT/ICT related benefits and challenges at several levels. So understanding the situation of design process and design culture dealing with IT/ICT is vital for design researchers.

The other important cause is globalization. With progressive globalization and specialization trends within the building industry, collaboration among design stakeholders at 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 AEC firms in the developed countries. Design of Boeing 777 (Dietrich, Stephans, and Wald 2007) which comprises 10,000 designers in 238 teams scattered all over the world across 17 time zones is a very good instance for this working phenomenon.

To address the issue of collaboration in distant locations and to support digitization of the architectural design process, Moum (2006) proposes to use high-tech visualization techniques and media. On the other hand, Fruchter (1998) recommends that integration of design and construction process can better support collaboration among team members. Moreover, she states that integration has major advantages in decreasing labor and material costs during current comprehensive production procedures. Indeed, both digitization and integration are already achieved for all different stages of building design process except where the early phases of problem finding, analysis, and conceptual architectural design phases fail in transformation from analogue to digital. Existing literature links this failure to some inherent characteristics of existing Computer Aided Architectural Design (CAAD) tools which do not suit to minimum requirements of conceptual architectural design process in intuitive ideation.