VISUAL REASONING IN FACILITATING TRANSFORMATIONAL MOVES AS DISCERNED FROM SKETCHES IN ARCHITECTURAL DESIGN

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DEDICATION

To my kind wife who stood beside her husband at every single step of the way,
To my beautiful daughter who was patient for her father's targets,
To my beloved mother and father who constantly encouraged
their son to continue his education,

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ABSTRACT

Productive transformation in the architectural design process is vital in generating and developing nascent concepts and ideas that transpire through the many phases of designing. Through sketches, designers could potentially seek and create more desirable and sustainable forms by transforming previous images through various cognitive techniques such as visual additions, deletions, and modifications. The aim of the research is to propose a design reasoning framework of visual cognition for the development of design expertise in the architectural studio environment. The current study compares the sketching and design transformative skills (DTS) between selected third- and fifth-year undergraduate students of architecture. Fourteen architecture students from Universiti Teknologi Malaysia (UTM) were involved in the observations, with seven respondents each from the groups of third- and fifth-year students. This was undertaken by observing and analysing the outcomes of student sketches, as they develop designs for a proposed gallery building within a stipulated two-hour task session and based on parameters and limitations outlined in the design brief. The whole exercise undertaken by each student was captured on video through a High Definition camera, and the results were then collated, encoded, segmented, tabulated, and analysed. A retrospective protocol analysis method was then applied to examine the sketch data gathered from all the design tasks performed. A non-parametric testing method was applied to determine whether or not there were significant differences in the nature of the design transformation activities between the specified student groups during observation. Substantial findings were obtained based on the analyses of differentiated ability in the design transformations between the two groups of undergraduate students. The study reveals that the fifth-year students utilised the vertical move (convergent thinking) more than the third-year students when it came to refinement design. In contrast, the vertical move occurred for a longer duration for the third-year students compared to the fifth-year students in regard to detail design. Potentially, the study provides a means for enhancing student ideation and conceptualisation capabilities through a productive design process. This study further benefits future planning and implementation towards a more effective design education and training process.

ABSTRAK

Transformasi produktif dalam proses rekabentuk senibina adalah penting dalam menjana kreativiti dan memupuk konsep serta idea yang berlaku dalam pelbagai fasa rekabentuk. Melalui lakaran, perekabentuk berupaya mencari dan melahirkan bentuk-bentuk yang lebih menarik dan lestari melalui transformasi imej yang melibatkan pelbagai kaedah kognitif seperti penambahan, pengurangan dan pengubahsuaian visual. Tujuan kajian ini adalah bagi mencadangkan suatu kerangka penaakulan rekabentuk berasaskan kognitif visual untuk pembangunan kepakaran rekabentuk dalam persekitaran studio senibina. Kajian ini dilakukan bagi membandingkan kemahiran dalam lakaran dan transformasi rekabentuk diantara pelajar senibina tahun ketiga dan kelima dalam pengajian sarjana muda. Seramai empat belas orang pelajar senibina dari Universiti Teknologi Malaysia (UTM) telah terlibat di dalam kajian tersebut, tujuh orang daripada pelajar terpilih terdiri daripada kumpulan pelajar tahun ketiga sementara tujuh orang yang lain merupakan kumpulan pelajar tahun kelima. Usaha ini melibatkan pemerhatian dan penganalisaan hasil lakaran-lakaran pelajar-pelajar senibina dalam usaha mereka membangunkan cadangan rekabentuk sebuah galeri dalam tempoh 2 jam dan dengan mengambilkira parameter dan kekangan seperti yang dinyatakan dalam arahan rekabentuk. Tugasan ini telah dirakam melalui kamera video berdefinisi tinggi dan hasil dapatan daripada video pemerhatian tersebut telah dikumpul, dikod, disegmen, dijadualkan serta dianalisa dengan menggunapakai kaedah protokol restrospektif. Kaedah ujian bukan parametik telah digunakan bagi mengenalpasti perbezaan ciri-ciri aktiviti transformasi rekabentuk diantara kumpulan pelajar yang terlibat dalam pemerhatian tersebut. Penemuan penting telah dibuat berdasarkan analisa bagi perbezaan keupayaan dalam transformasi rekabentuk diantara kedua-dua kumpulan pelajar sarjana muda tersebut. Kajian ini telah menunjukkan bahawa pelajar senibina bagi pengajian tahun kelima lebih banyak menggunakan tindakan yang bersifat menegak (pemikiran tertumpu) daripada pelajar dalam pengajian tahun ketiga pada fasa pemurnian rekabentuk. Sebaliknya, tindakan menegak ini berlaku dalam jangkamasa waktu yang lebih lama dikalangan pelajar tahun ketiga berbanding pelajar tahun kelima dalam fasa perician rekabentuk. Kajian ini berpotensi mempertingkatkan keupayaan pelajar dalam pembentukan idea dan konsep melalui proses rekabentuk yang produktif. Selanjutnya, ia turut berupaya menyumbang terhadap perancangan dan perlaksanaan pengajaran dan latihan dalam rekabentuk yang lebih berkesan.

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LIST OF ABBREVIATIONS

FBS	-	Function Behaviour Structure
LTI	-	Link Type Indexes
LTIT	-	Link Type Indexes Tangential
LTIM	-	Link Type Indexes Modification
LTIS	-	Link Type Indexes Supplementary
DTS	-	Design Transformative Skills
V	-	Vertical Move
L	-	Lateral Move
DU	-	Duplication Move
AD	-	Adding of Detail
L-A	-	Lateral A (Ambiguity Sketch)
L-R	-	Lateral R (Revise)
L-S	-	Lateral S (Different Solution)
RE-S	-	Redrawing in Same presentation Types
RE-D	-	Redrawing in Different presentation Types
CO	-	Copy
DE	-	Definitive
DI	-	Diagram
PR	-	Preliminary Design
RE	-	Refinement Design
DE	-	Detail Design
GF	-	Ground Floor
FF	-	First Floor
SI	-	Site Plan
SE	-	Section
EL	-	Elevation
PE	-	Perspective

NON	-	No Movement
CIM	-	Cognitive Interaction Matrix
DTM	-	Design Transformative Matrix

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Visualization is a significant medium in the design process. Visualization by providing a means to discover design problems and potential solutions facilitate successful design. Visualization is, in fact, the visual mental images employed by the designer throughout the design process, which facilitates the information‘s generation, interpretation, and manipulation, via spatial representation. Roozenburg and Eekels (1995) stated that visualization assists designers in different aspects such as recognizing the design problem, raising design solutions for the problem and lastly evaluating the developed solutions. Visualization can be applied through mental imagery and physical instruments such as sketch, computer and model making.

The perception of a sketch assisting in producing a mental image that may, in turn, generate more sketches that have the possibility of producing other mental images is a process known as reinterpretation. Reinterpretation is a precious source of new and unanticipated ideas that could be considered as the outcome of lateral thinking process (De Bono, 1970).

In the primary phase of the design process, sketch has a crucial role among the traditional mediums, and is the elementary depictive action performed by designers during the design process. Garner (1990) mentioned that sketching fundamentally effects the development, creation, evaluation and distribution of the ideas. Moreover, Goel (1995) suggested that by being “syntactically” and “semantically” unclear and ambiguous, sketches influence the heuristic, creative, open-ended stage of problem-

solving. Some researchers such as Fish and Scrivener (1990), Goel (1995) and Goldschmidt (1991) came to the conclusion that "Rough and untidy sketching" allows the designer to work quickly, suspending judgment on polished features. Moreover, it could help in generating new ideas. Purcell and Gero (1998) stated that in design perception research, substantial effort has been concentrated on the roles of free-hand sketches in the conceptual design process and their relationship to designer's cognition. The important theme of visual thinking in the process of designing is how shapes are recognized from sketches and how they are transformed into different forms by designers (Huang, 2008). Verstijnen et al., (1998) suggest that sketch consists of the design elements which fix the other ones through fundamentally transforming them.

1.2 Research Background

In design, visualization signifies the visual mental images employed throughout the design process via the designer. By the aid of spatial representation, visualization simplifies the generation, interpretation, and manipulation of information. To express it another way, visualization is the cerebral images that the designer applies when carrying out a design task. According to Roozenburg & Eekels (1995), visualization empowers the designer in understanding the design problem, developing design solutions for the specific problem, and evaluating the possible solutions that have been developed. It is among the most significant appliances in the design process. It simplifies the prosperous design by presenting a means to discover design problems together with possible solutions (Dahl, Chattopadhyay, & Gorn, 2001). In order to specify a design object's visual form, design thinking will require visual representation. According to Mckim (1980), representational procedure like sketching by employing the interaction of factors as seeing, imagining and drawing will facilitate visual thinking.

Complementary research has demonstrated how visual representations support the sequential and cyclical processes, and how design thinking performs via expressed representations in visual reasoning (R. Oxman, 2002). "Design reasoning" is a thinking

prototype that utilizes the design rules and "reflection-in-action" process (Schön, 1988). Schon and Wiggins (1992) proposed that designers initially "see," and later "move," design objects. "Seeing- moving" are the sequences of the design and seeing the unintended consequences of moves cause the designer to use with the complexity of ill-defined problems (Schon & Wiggins, 1992). On the other hand, Goldschmidt (1989, 1995) believed that "moves" and "arguments" are divisions of the "design processes." Sketching activities are correlated to moves in terms of whether the designer is concerned about a sketch and "reading off" a sketch, and if the sketching within a move is active enough or not. Many studies of the externalization of design thinking in sketching and drawing have widely authorized the "seeing–moving–seeing" model.

Sketch is an essential element in design activity, which, by saving the design solutions, free the designer's memory from the additional load; it also appears to be vital for identifying potentials and conflicts (Akin, 1978). The conceptual phase of the design process and the sketching role has been examined comprehensively by the design research literature (Goldschmidt, 1994; Purcell & Gero, 1998; Suwa, Purcell, & Gero, 1998; Suwa & Tversky, 1997). They highlighted that sketching is like a cognitive tool, which perform, similar to a dialog. Counting the sketches as cognitive tools, Oxman (1995) expressed sketches as behavioural reactions to visual-mental processes, which have the capability to be viewed and interpreted: "The sketch is seen as the basis of a visual and mental transaction between the designer and the representation. It is these transactions with the external representation that illuminate the visual-mental processes of designers" (93). The factor that makes free-hand sketches important in the design activity is that free-hand sketches become a vital medium in the dialectical process of designers (Goldschmidt, 1991; Schon & Wiggins, 1992). Sketches are declared to be external representations in the role of support for externalized thinking (Do, 2002) and in addition, sketches as a cognitive tool are developed to help memory and simplify thinking (Tversky, 1999). The research on protocol analysis is concentrated more on the sketches' role and usage in the initial phase of conceptual design. The significant role of free-hand sketches in design activity is that these sketches perform as a vital medium for dialectic process of designers (Goldschmidt, 1991; Schon & Wiggins, 1992).

The sketches move from unstructured drawing to further detailed and precise illustrated representations. The design stages move from the initial phase to the refinement phase and finally to detailed design, a noticeable rise in the level of detail is observable throughout these phases. (Goel, 1995). Lateral and vertical transformation are the two design transformation types defined by Goel (1995). Lateral transformations occur once one idea moves towards a different idea while vertical transformations are those that happen when one idea is moved to a more detailed one (Goel, 1995). Principally, lateral transformations are linked to unstructured drawings and take place in the primary phases of design while vertical transformations are related to further detailed and accurate sketches and befall during the refinement and detailed design stages.

Goel (1995) also defined three-design movement as vertical, lateral and duplication move, which the third one defined as "a movement from one drawing to a type-identical drawing".

He discussed that a particular symbol system's form is organized by sketching, which is classified by semantic and syntactic density as well as ambiguity, and the lateral transformation occurs due to these sketching features. In contrast to sketching, the computer drawing software is unambiguous and non-dense and subsequently would cause difficulties in lateral transform (Goel, 1995).

Transformation is the mechanism that shows the way new designs generate from unambiguous representations, the prevailing products and their embedded rules and structures. Moreover, this is the design that seeks to create desirable and sustainable changes in form (Tovey, Porter, & Newman, 2003). In order to transform descriptions in a cyclic style, the designer employs a set of quick sketches. In this cyclic manner, images are generated in mind by sketches, by which the embodied themes in the design are developed. Sequentially, this directs the designer to transform the former image through additions, deletions, and modifications (Tovey et al., 2003).

The aim of design education is to allow the students to attain a certain phase of design ability (Dorst & Reymen, 2004). In general education, it is mainly important

that teachers have an essential understanding of the abilities that they are looking for to improve in their students. In addition, “teachers can get by as long as their students are reasonably competent enough to enter their profession at the end of their course” (Cross, 1990). There are several directions for the further development of this design expertise model. This knowledge about the explicit processes of problem solving and reflection that occur at different levels of design expertise can help researchers define and study the transitions that link the different levels (Dorst & Reymen, 2004). What does a designer require to learn to get from one phase to the next? What are the situations in which leaps can happen?

For many domain-specific activities, expertise is assessable through different phases of improvements in skills and performances. For instance, some researchers on chess skills strongly propose that there are differences between expert, master, and non-expert players in terms of organizing, retrieving and utilizing knowledge from memory (Chase & Simon, 1973; De Groot & de Groot, 1978). The differences of novice and expert were also mentioned in the conceptualization, categorization, and representation of physics problems (Chi, Feltovich, & Glaser, 1981). Differences in expertise are not spontaneous phenomena. It appears that outstanding performers develop their expertise levels through the deliberate development of domain-specific performances and skills (K. Ericsson & Simon, 1993).

According to Dorst (2004), there are five levels of expertise that correspond to five ways of perceiving, ranked in order of expertise. He acknowledges the influence of the discussion with Dreyfus (2003) on his classification. ‘Novice,' ‘beginner,' ‘competent,' ‘proficient’ and ‘expert’ are the levels of this classification. Dreyfus (2003) presented a model that classifies six different levels of expertise including ‘novice’, ‘advanced beginner’, competent’, ‘expert, ‘master’ and ‘visionary’ which are parallel with ways of recognizing, structuring, and solving the problems. Hubert Dreyfus’s model of general problem-solving strategies identifies levels of expertise in terms of skills in perceiving, interpreting, structuring and solving problems (Dorst & Reymen, 2004). The model of Dreyfus was recently expanded by Lawson & Dorst (2005, 2013). They incorporated specific skills to design activities to expand Dreyfus models. Furthermore, for achievement of design expertise, they expressed two principal situations. Firstly, to ‘trigger’ a change among adjacent level of expertise, it

is essential for designers to access adequate knowledge. Secondly, the transformation between design expertise's levels might occur with conscious performance of designers via applying new methods besides being assisted by others in 'perceiving' and 'acting' (Lawson & Dorst, 2005).

Previous study measured and analysed sketch in different context as an overall process, drawing presentation types and levels of detailing to have an in-depth view of the behaviour of designers in sketching. M. Kavakli and Gero (2001) investigated differences in the balance of cognitive actions between novice and expert in overall process (during the design process). Moreover, Goel (1994, 1995) classified development of design to the levels of detailing: "Preliminary-design" which create some solution options and core ideas, "refine design" which improve current sketch by transformation and "detail design" where design of the product takes place. In addition, Do, Gross, Neiman, and Zimring (2000) and Bar-Eli (2013) mentioned several drawing presentation types (types of project), as elevation, plan, elevation, section and perspective.

1.3 Problem Statement

One of the important current discussions in design and design process is visual reasoning. More recently, literature has appeared that offers contradictory findings of visual reasoning through internal memory (mental imagery) and external memory (sketching and computer software).

Mast and Kosslyn (2002) investigated the reinterpretation of vague shapes in imagery. In their study, they had a measurement on personal key mental imagery abilities and for this purpose, 44 participants were examined. Observation led to the conclusion that objects in the mental image may be ambiguous, and at least some people can reinterpret previously unrecognized objects (Mast & Kosslyn, 2002). Moreover, Chambers & Reisberg (1985, 1992) argued that people have problem in reinterpreting the shapes in mental images thus mental images are more like description than delineation. They stated that because novice students are limited in

mental imagery in terms of ‘reinterpreting’ the images, their mental imagery cannot be aided by sketches. In the conceptual design process, expert designers could use their imagery more effectively than the novice and due to slowing down the ‘cognitive activity’, the novice’s image generation is slow. Thus the reason may be in the parallel processing of cognitive actions (Chambers & Reisberg, 1985, 1992). In this respect, Bilda, Gero, and Purcell (2006) in their investigation were assisted by 3 experts who worked in 2 separate design processes of ‘sketching and not sketching’. The results and comparison of design activities were derived from protocol analysis and did not show any significant difference between sketching and not sketching. Thus, they concluded that externalizing a design may not be the only way to design visually and for expert architects sketching is not a crucial action in the early stages of conceptual designing and experts could progress in design by thinking only (Bilda et al., 2006). According to above evidence, novices cannot easily reinterpret object in mental imagery. Therefore, sketch is essential for them in the early step of design process (Helmi &Khaidzir, 2016). This study raises the question: do novice students have problems sketching?

In the first challenge of novices’ sketch, Fish and Scrivener (1990) proposed that although paper-and-pencil sketching is flexible, it has a limited capacity for generating and amplifying the mental imagery due to the short duration and small spatial capacity of working memory (Fish & Scrivener, 1990). Moreover, M. Kavakli and Gero (2001) expressed despite the fact that the novice’s sketch are less successful in supporting ‘mental simulation’ than the expert’s, in the early stage of the conceptual design process the novice’s perceptual activity is twice that of the expert’s. Furthermore, Andjomshoaa, Islami, and Mokhtabad-Amrei (2011) indicate that most of the students had “basic mistakes” in sketching. Furthermore, Verstijnen et.al (1998) by evaluating the execution of expert and novice designers deduced that only the expert designers were able to use restructuring through sketching. In addition, expert architect is not affected by sketching due to effective imagery; however, novice students require sketches to ease object reinterpretation in mental imagery.

As the second challenge, M. Kavakli and Gero (2001) investigated the imbalance in cognitive activity between expert and novice designers and came to the conclusion that the expert generated sketching pages equal to more than three and a

half times that of the novice, thus the expert is more active than the novice. They performed an examination comparing the novice students and expert designers, in which the expert designers produced 7 alternatives whereas the novice students had 2, thus they concluded that that alternative interpretation's perception and spatial relations' organization may consume more time for the 'novice' than 'expert designers'(M. Kavakli & Gero, 2001). Moreover, Atman, Cardella, Turns, and Adams (2005) stated that that seniors produced higher quality solutions, considered more substitute solutions and made more transitions among design phases than the freshmen (Atman et al., 2005).

In summary, novice students have problems in reinterpreting visual object in mental imagery, and their sketches could not support their mental imagery; moreover, they cannot transform design between design steps easily. In addition, design expertise is an important issue since understanding differences in sketching skills in levels of expertise are having an essential effect on the development of designers. Lawson and Dorst (2005) stated that intentionally enabling and instigating changes among expertise levels are vital subjects in design education and design training. In consequence, the research problem is that, although it is obvious that different levels of design expertise are different in the case of design activity and sketching skills, it is not clear what differences exist in levels of design expertise. This study raises the question of what are the differences between levels of design expertise.

1.4 Research Gap

From the review of various studies, some gaps could be identified from some domains under transformation in design. Most studies so far have used protocol to investigate seeing, cognition and thinking of designers (Cross, 2001; K. Ericsson & Simon, 1993; Suwa et al., 1998), However, there has been little discussion about design movement and design transformation. Goldschmidt defined a movement as: "a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move" (Goldschmidt, 1995a). Moreover, reviewing literature of design transformation shows that some research describe vertical and lateral

transformation, levels of detailing, shape rules and drawing action (Abdelmohsen[1] & Do[1], 2007; Goel, 1994; Prats, Lim, Jowers, Garner, & Chase, 2009; Rodgers, Green, & McGown, 2000). However, only a few studies in the case of transformation have been carried out in small numbers in this area, such as samples size of one or two. Some of them use small sample size to define or develop a method (Cai, Do, & Zimring, 2010). However, there is little systematic and methodical study in differentiating design transformation between two levels of design expertise (Goel, 1995; M. Kavakli & Gero, 2001). There is lack of study in using application of drawing action in understanding how design is transformed between third and fifth year students (Tables 1.1 & 1.2). The purpose of current research is to establish a design reasoning framework of visual cognition for development of design expertise.

Reviewing literature and investigation of design shows some researchers use protocol analysis to describe design thinking, and there is lack of study in using design transformation skills (DTS) based on drawing action to determine difference of design expertise, most notably among undergraduate students of architecture. The implication of this study would be fundamental to design education in training academic programs (Table 1.3).

Table 1.1 : The findings of previous research in case of design transformation and actions

Author	Subject	Parameters	Finding
Cia and Do (2010)	Impact of inspiration source in creative design	Links base on vertical and lateral Inspiration source: Textual description, diagram, floor plan, exterior sketch rendering, exterior photo	The more creative the design is, the more chunks, higher number of design alternatives and webs are presented in the 'extended linkograph.' The frequent repetition of design object of the prior move is an indication of fixation. They found sketch renderings and textual descriptions beneficial in enabling innovation and not causing primary fixation.
Vinod Goel (1994)	Design development	Transformation types: vertical &lateral Design development category (degree of abstraction):	He defined two types of design transformation: vertical and lateral transformation. Vertical is used for deepening of the problem space, and lateral are used for widening the problem space and exploration of kernel idea. He define 3 design development as degree of detailing; Preliminary design, Refinement design, Detail design
Rodgers, G. Green, A. McGown (2000)	Track design progress	Transformation types Levels of complexity	Good design is a consequence of the balance between *vertical and lateral* transformation at these primary phases rather than an extreme *lateral* bias.
Masaki Suwa & Barbara Tversky (1997)	Perceiving design sketches	Decomposing entire protocol to focus-shift segments and continuing segment	Decomposing whole of protocol to "continuing segment" and "focus-shift segments" Students had less and shorter dependency chunks than architects, shows that once architects moved their focus of attention, they thought more deeply about the topic.
Sherif Abdelmohsen[1] and Ellen Yi-Luen Do[1] (2007)	Tracking design development	Transformation: vertical and lateral Stroke: transfer, blocked, added	They defined a set of process types; cross propagation, lateral promotion, and vertical promotion, which describe the behaviour of individual strokes.