An Investigation of the Influence of Using the Computer on Cognitive Design Actions:

A Protocol Analysis on an Expert and Novice Designer

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Abstract. *This paper documents a research pilot study; it is a comparative investigation between an expert designer and a novice designer. The study used protocol analysis to examine design cognitive actions whilst using 3D digital media during the conceptual stage of design. The empirical study found novice designers capable of managing a design process of complex objects due to the increase in their contribution of design strategies to the overall process. The possible reason for this may be due to using free-form modelling with accuracy aids found in computing facilities. This provides evidence to suggest automated computing should be encouraged within the pedagogical framework of architectural design.*
Keywords: *Protocol Analysis; Design cognition; Complexity Management; Design Process.*

Introduction

Architecture is distinguishable from other fields of design 'it is inherent of rich representations, indiscriminate use of inventive strategies, non-standard problem composition schema and strategies of complexity management' (Akin 2001). Cognitive actions include processing visual images in design, storing, classifying and transforming them and creating generic knowledge for retrieval of design information.

Cognitive processes inherent in architectural problem solving are perceived and interpreted idiosyncratically depending on the designer's understanding of a design situation. This paper is an attempt to characterise design through the study of cognitive actions and design behaviour using Protocol Analysis to understand the transformation of internal and external representations during the conceptual stage of design. Protocol Analysis is a research methodology that documents and examines verbalised and non-verbal activity during a simulated real problem solving task.

It is possible to categorise the difference between novice and experts in terms of: productivity, rate of cognitive activity, structure of concurrent actions, number of cognitive processes and groupings and strategic knowledge (Gero 2003). Gero & Kavakli (2002) investigated concurrent cognitive actions of novice and expert designers concluding that 'expert's cognitive actions are clearly organized and structured, there are many concurrent actions that are hard to categorize in the novice's protocol.

The detriment of the novice exploring many avenues and performing a relatively higher percentage of concurrent cognitive actions is that it is too much for the human short term memory to handle. Architects work iteratively between problem analysis, solution generation and evaluation, this iterative process is a human way of making complexity more manageable (Akin, 2001). V. Goel (2001) believes there to be two types of knowledge associated with design cognition: Type 1; explicit, domain specific, for instance concerned with technical issues and Type2; inarticulate, domain independent that supports ill-structured representation and aids managing processes of design.

Complex images or 3D models are not retrieved whole from long-term memory; rather they are constructed from a collection of imagery information about the object of interest. These different functional capabilities have only been partially explored (Eastman, 2001). Oxman (2002) a protagonist in this field has explored the construction of knowledge networks of design using 'computer-based diagrammatic model, as a pedagogic technique for fostering design understanding.'

Design Experiment

The design experiment uses protocol analysis to investigate the difference between expert and novice designers during a conceptual design stage. In particular, it examined the effect when using 3D NURBS (Non-Uniform Rational B Spline) software, Rhino, on cognitive processing in terms of design problem solving.

Participants include an expert (qualified architect) and a novice (first year architecture student). Prior to the design task, Rhino sessions focused on complex & free-form modelling using design exercises as a medium for critical thinking. It should be noted that the expert designer had less automated skill using this software. To compensate, during the design experiment participants were free to ask instructional advice. However, the ratio level of Rhino skill of each participant is taken into consideration within the analysis.

Protocol analysis and qualitative analysis

Data collected from the pilot study included Protocol Analysis recordings from the design task and representations, this data was supported with participant previous design experience and their experience using different media as design tools. Following the recorded design, participants were asked to reflect on their performance in a short informal discussion and a more detailed questionnaire. This paper focuses on protocol results.

During the design task, participants were asked to prepare a 3D digital model for a discussion with their client or tutor. The experimenter's role was to assist and instruct Rhino queries, time notification at 10 min intervals, and prompt verbalization during prolonged silences and to make no contribution to design content.

The design task was set during conceptual design phase; this is considered to be informal yet complex due to variations in levels of design abstraction and the ability to manipulate much information within a short time period. The brief was based on a small scale, real design task and was devised to test architectural accountable design issues such as form, function, scale, construction, materiality, spatial experience and contextual issues.

Design Brief

Make a proposal for a Pedestrian & Cyclist Bridge. The design should allow provision for a Shelter to be sited at its connection with the river edge or integrated within the bridge's public realm. It is the conceptual stage of design and your aim is to develop a three-dimensional (3D) computer model in Rhino. This model should represent the spatial and architectural qualities of your design.

Design requirements / restrictions:

- Allow for river traffic under with a width 15m x height 10m.
- Improve pedestrian & cyclist connectivity with existing routes.
- Consider construction and materiality of the bridge and shelter.
- There are no cost restrictions at this stage.
- You should consider scale.
- Express three-dimensional spatial qualities of your design.
- Consider how the bridge and shelter will protect or expose pedestrians and cyclists from the elements.

Interpreting & analysing the data collected

The analysis seeks to find correlations between the designer's process exhibited and assumptions associated with expert and novice design behaviour. It questions novice's exhibited process, their structure and ability to manage complexity of design processing. It considers the correlation between number of fragments and quality of design solution.

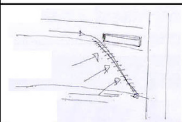
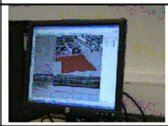
Verbalisation during the design task was interpreted using a simplified coding scheme (See Table A1 and A2 in Appendix) which deals with design information and design processes. The customised coding scheme is founded on other models used by Kim et al (2006) and Suwa and Tversky (1996). Dialogue was fragmented into pieces and documented with concurrent actions such as 3D digital modelling, sketching or hand gestures. Table 1 below is an example of the expert's dialogue 7min into the task, where he arrived at a solution at this early stage using sketch, referral to brief and digital context model concurrently:

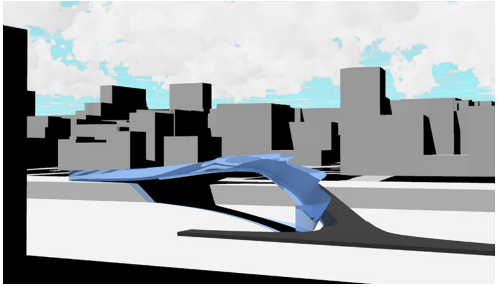
Comparison of quality of solution

Three independent examiners critiqued the design solutions based on a matrix (1-5) relative to each task requirement, accompanied by comments on their scoring decision. In the case of the novice's design solution, one examiner commented on the 'over-engineered' structure concluding it was not an appropriate scale for pedestrian bridge. In contrast another examiner felt it could be viewed as a 'landmark' due to the high visibility of the structure but did question whether this was appropriate for the site. The solution derived by the expert designer appeared to be more resolved and examiners commented that it was easy to understand, with distinct elements and a clear concept, illustrated in Figure 1 and Figure 2.

From the three examiners, the expert received scores; 18, 19, and 23 with an average 20 points whereas the novice scored; 11, 18, and 17 with an average 15.3 points. Although the average score of the novice is less, individual grading illustrate that the novice is capable of a quality of design comparative with an expert designer. Results show that the expert achieved consistent quality across the requirements whereas the novice's results were more sporadic. Although this then instigates us to query the novice's standard of cognitive actions alongside their ability

Table 1
Expert designer; example record of design actions.

Time	Design Process code	Design Information code	Verbalisation	Sketch	Rhino
7.10 min	Sp	Fs & Bp	If a bike is coming along here, then the direction of the bridge would need to be coming across, not so much at a straight, but at an angle.		
7.30 min	Sj	Ce & Bp	Which would probably be quite a buffer against weather and exposure, otherwise people would get blown off the bridge.		



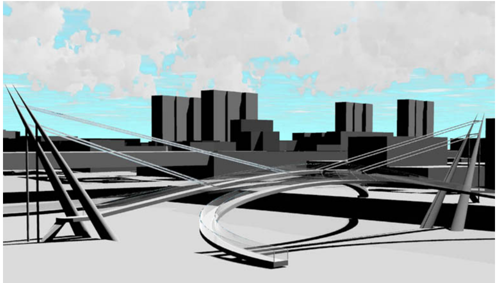


Figure 1
Expert Design Solution.

Figure 2
Novice Design Solution.

to produce high standard design.

Design activity

It should be noted that the expert spent twice as much time as the novice on instruction. However, this has been taken into account and for the purpose of this study; instructional dialogue has been omitted from Table 2 illustrating the fragment percentage contribution by each participant to their overall design process. For the purpose of this study; an information fragment is a piece of dialogue that is continuous for a period when the design content remains the same.

Design Information	Expert	Novice
General	20 (48%)	46 (49%)
Specific	21 (52%)	48 (52%)
Total	41	91

Table 2
Fragment percentage participants contributed to their overall design process.

The expert performed 61 fragments during the 90min design task whereas the novice performed approximately 3.09 times more totalling 198 fragments.

The novice carried out more fragments evaluating a solution, and it could be suggested that design inexperience contributed to an increase in evaluation activity. The results indicate there to be no significant difference between the expert and novice percentage of fragments during Problem analysis, and Design Strategies. However, the expert contributed a higher percentage of their own distribution to solution in comparison to the novice. Additionally, when Design Strategy contribution is further investigated, differences arise in the experts and novice percentage of Process Management resulting in 14% and 30% respectively. This could suggest that the novice carries out more design strategies as a coping mechanism, thus exhibiting complexity management traits due to the large number of fragments and high rate of cognitive actions. This is a necessary to do otherwise it jeopardizes the ability to process information as is humanly possible by short term memory. Evidence of this is seen during the 34thmin and 46th min. Following the generation of many alternatives the novice designer expresses a concern in the ability to deal with the amount of information and commented:

“There’s so many things that could make it go, like, a wee bit skew-wif at the minute”

“I’m not thinking at the moment, I’ve got a brain freeze”

However, taking into account the novice’s expressive concerns over managing a complex process, results from the quality of solution suggest he was successful in this endeavour. The comparative larger percentage of Process Management could be said to have a positive effect on the designer’s Type 2 knowledge, as recognised by Goel, helping to encourage those cognitive functions associated with managing processes of design.

Design approach

On reflection, the expert perceived using the computer as a visualisation tool to help develop design during a process-orientated approach where he generated many solutions and chose the best solution later. Whereas the novice designer perceived using the computer as a design strategy tool to help manage design complexity during a solution-orientated approach where he generated one main solution and made adjustments to this.

Results from the protocol analysis provide evidence that the expert generated a conceptual solution within the first 7min and continued to use the computer to visualize an idea making few adjustments to this. Unlike the novice, who spent less time on any one design activity and instead iteratively alternated between different activities, making many adjustments to partial solutions. Figure 3 and Figure 4 demonstrate the participant's distribution of design activity throughout the 90min period.

The figures above illustrate the difference in the number of design actions. The expert exhibits a structured process, beginning with problem analysis, followed by solution generation and later evaluation. The expert exhibited clear grouping of design information and a structured process. Contrastingly, the novice jumped to and from different content categories of design information, as anticipated, throughout the 90min period providing evidence of an unstructured process.

Design Information

Table 3 indicates there to be no significant difference in the percentage of distribution of level of abstraction during information fragments between the expert and novice.

The novice performed 3 times more fragments (198) than the expert, with a total of 91 references to a class of design information (see Table A2 Design Information Coding Scheme), whereas the expert totaled only 61 fragments with 41 references to a class of design information. This suggests that the

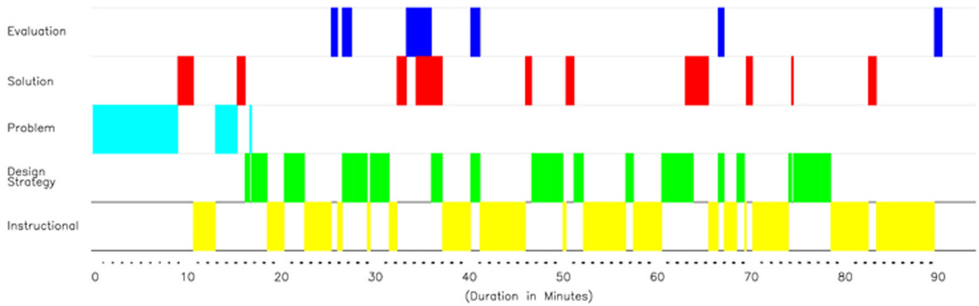


Figure 3
Expert Design Activity during the 90min task.

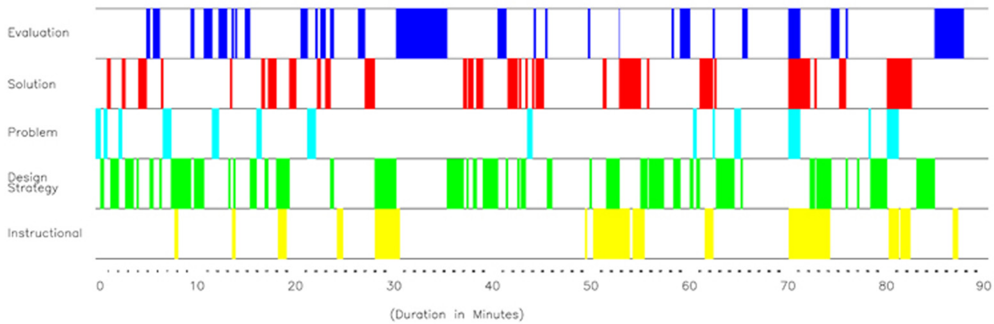


Figure 4
Novice Design Activity during the 90min task.

Design Cognitive Activity	**Expert** Fragment %	**Novice** Fragment %
Evaluation	13%	21%
Solution	31%	25%
Problem	10%	10%
Design Strategies	46%	44%

Table 3
Number of Fragment with Design information and its respective percentage of General and Specific content

expert demonstrated a more efficient design process, performing a higher rate of design information/fragment than exhibited in the novice's unstructured process.

Findings and tentative conclusion

This paper investigated novice and expert designers, in terms of design cognition, using protocol analysis. The quality of design solution was compared; the preferred solution was produced by the expert. However, aspects of the novice's solution demonstrated capabilities of producing a complex design on a par with the expert designer. In turn, this provoked the subsequent analysis which investigated their comparative cognitive actions.

During the design task the expert exhibited a structured and efficient design process, whereas the novice proved unstructured and less efficient. However, the novice design solution was successful; the reason for this may be due to a larger percentage of Process Management contribution to the overall design process. Both participants applied a different design strategy, the expert preferred to use sketch to generate ideas and utilized the computer as a visualization tool, denying it any contribution to design development, whereas the novice embraced the use of the computer as a design strategy tool.

The protocol analysis experiment highlighted the closing gap between expert and novice ability to produce complex design solutions using computers. It provided evidence that computing supports the management of design process complexity, enabling novice designers to develop other knowledge structures found in Type 2 knowledge, thus helping to manage ill-structured problem representations.

The results indicate that the use of accurate, free-form modelling, such as Rhino, during design activity has a positive influence on the design behaviour. In particular, it appeared to aid the novice's ability to manage design process of complex objects which would otherwise prove detrimental to the success of a complex design solution. Hence, with automating computing skill there is a potential to foster cognitive functional capabilities, helping to manage process complexity and whilst still retaining other positive attributes of novice behaviour, such as unhindered creativity. This should be encouraged within the pedagogical framework of architectural design.

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Table A1
Design Process Coding Scheme

Primary Class	Secondary Class	Code	Description/example
Problem analysis (question set for solution)	Analysing	Pa	Understanding design task and requirements
	Gathering	Pg	Collecting data about user or context information
	Clarify	Pc	Defining design constraints and objectives
Solution generation (answer to problem)	Generate/proposing	Sp	Generating idea for partial solution
	Judge	Sj	Evaluating ideas and data
Evaluation (decide/judge value)	Elaborate	Ee	Realising, finding technical solution
	Analyse	Ea	Assessing the solution
	Refine	Er	Improving the solution
Design Strategy	Process management	Pm	Controlling design activities
	Rhino management	Rm	Controlling Rhino related activities e.g. organise layers
Experimenter & Instruction dialogue		X	Think aloud prompt, Time reminder & Rhino instruction

Table A2
Design Information Coding Scheme

Primary Class	Secondary Class (includes level of abstraction)	Code	Description/example
Context	Built environment	Cb	Traffic infrastructure & buildings
	Environmental	Ce	Wind, river
User	Physical –user action	Bp	Physical usability by pedestrians and cyclists
	Mental – user feeling	Bm	Experiential qualities by pedestrians and cyclists
Function /requirement	General feature	Fg	Essential condition – allow for river traffic
	Technical realisation	Ft	Creating a component to allow for this
Form	Overall shape	Fs	Using a curved shape
	Component shape	Fc	Shape of a component i.e. handle
Structure/materiality	General	Sg	General related to structural and material
	Component	Sc	Detailed related to structural and material elements