Cognitive Biases in Design

Joo-Hwa BAY
STELLINGEN

Bijlage bij de thesis:
Cognitieve Biases (Illusions) in het Ontwerp.
Het geval van de Tropische Architectuur.
Joo-Hwa BAY

1. Als computers zonder cognitieve biases (illusies) zijn, zouden we ze moeten gebruiken om in ontwerp-wedstrijden te oordelen.
3. Het aanleren van gevestigde ontwerp-waarden kan zulke studenten met zwakke natuurlijke vermogens niet helpen, omdat zij waarschijnlijk niet in staat zijn om ze aan te leren.
4. Ontwerp-studenten in opleiding die ontwerpen volgens de verwachtingen van het instituut, zullen er toe neigen om te ontwerpen volgens de verwachting van de opdrachtgever als ze afstuderen.
5. Een goed ontwerp bewaart het evenwicht tussen de wensen van de opdrachtgever en de ontwerper.
7. Indien genoeg aangeprezen en onderricht aan studenten en het publiek, kunnen architecturale mythes eigenschappen worden waarvan kan worden genoten en die zelfs deel kunnen uitmaken van het menselijk gedrag.
8. Het herkennen van een wenselijk ontwerp houdt niet per se de mogelijkheid in om een gelijktijdig ontwerp te maken, of een geschikter ontwerp.
9. De mogelijkheid om te "mis-conceptualiseren" (mis-kiezen / mis-catalogeren) is de sleutel voor creativiteit.
10. Om computers creatief te laten zijn, moeten we kunnen verzekeren dat ze kunnen "mis-conceptualiseren".
11. Creativiteit kan slechts in een culturele context herkend worden. Leer computers zo veel mogelijk kennis van de culturele context aan, als je wilt dat hun output als creatief herkend wordt.
12. Met het gegeven van de tijd en bepaalde oorspronkelijke structuren, ontwikkelde de Aarde zich tot haar gewenste vorm. Filosofen hebben het antwoord op de vraag wat de Aarde de kans en de voorwaarde bood om zich te evolueren, niet gevonden.

Vertaling Saskia Kloosterboer
PROPOSITIONS

Attachment to the thesis:
Cognitive Biases in Design
The Case of Tropical Architecture
Joo-Hwa BAY

1. If computers are without cognitive biases (illusions), we should use them to judge design competitions.
2. Some students of design cannot recognise good design. Their innate faculties are faulty.
3. The teaching of institutionalised standards of design cannot help the students with faulty innate faculties, because they are unlikely to be able to learn them.
4. Design students in school who design to the expectation of the institution, will tend to design to the expectation of the client when they graduate.
5. A good design is one that balances the desires of the client and the designer.
6. Some architectural theorists promote theories about design that only they can understand. They suffer the illusion that ordinary people behave or should behave according to their theories.
7. Architectural myths, if promoted and taught to students and the public often enough, can become commodities that can be enjoyed and become part of people's behaviour.
8. Recognising desirable design does not necessarily mean the ability to create a similar design or a more desirable design.
9. The ability to 'mis-conceptualise' is the key to creativity.
10. For computers to be creative, we need to ensure that they can 'mis-conceptualise'.
11. Creativity can only be recognised within a cultural context. Teach computers as much knowledge of the cultural context as possible if you want their output to be recognised as creative.
12. Given time and certain innate structures, Earth evolved into desirable forms. Philosophers have not found the answer to what gave Earth the chance and condition to evolve.
Cognitive Biases in Design

The case of tropical architecture
Cognitive Biases in Design

The case of tropical architecture

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ABSTRACT

Summary of dissertation

This dissertation investigates,

i) How cognitive biases (or illusions) may lead to errors in design thinking,

ii) Why architects use architectural precedents as heuristics despite such possible errors, and

iii) Develops a design tool that can overcome this type of errors through the introduction of a rebuttal mechanism. The mechanism controls biases and improves accuracy in architectural thinking.

The research method applied is interdisciplinary. It employs knowledge from cognitive science, environmental engineering, and architectural theory. The case study approach is also used. The investigation is made in the case of tropical architecture.

The investigation of architectural biases draws from work by A. Tversky and D. Kahneman in 1982 on “Heuristics and biases”. According to Tversky and Kahneman, the use of heuristics of representativeness (based on similarity) and availability (based on ease of recall and imaginability) for judgement of probability can result in cognitive biases of illusions of validity and biases due to imaginability respectively. This theory can be used analogically to understand how errors arise in the judgement of environmental behaviour anticipated from various spatial configurations, leading to designs with dysfunctional performances when built.

Incomplete information, limited time, and human mental resources make design thinking in practice difficult and impossible to solve. It is not possible to
analyse all possible alternative solutions, multiple contingencies, and multiple conflicting demands, as doing so will lead to combinatorial explosion. One of the ways to cope with the difficult design problem is to use precedents as heuristic devices, as shortcuts in design thinking, and at the risk of errors. This is done with analogical, pre-parametric, and qualitative means of thinking, without quantitative calculations.

Heuristics can be efficient and reasonably effective, but may not always be good enough or even correct, because they can have associated cognitive biases that lead to errors. Several debiasing strategies are discussed, and one possibility is to introduce a rebuttal mechanism to refocus the designer’s thinking on the negative and opposite outcomes in his judgements, in order to debias these illusions.

The research is carried out within the framework of design theory developed by the Design Knowledge System Research Centre, TUDelft.

This strategy is tested with an experiment. The results show that the introduction of a rebuttal mechanism can debias and improve design judgements substantially in environmental control. The tool developed has possible applications in design practice and education, and in particular, in the designing of sustainable environments.

Keywords:
Design bias;
Design knowledge;
Design rebuttal;
Design Precedent;
Pre-parametric design;
Tropical architecture;
Sustainability.
PREFACE AND ACKNOWLEDGEMENT

This study on the problem of design started in 1997 as a new direction of my personal interest in design theories. As a practicing architect for many years, and as a facilitator for learning architectural knowledge in education, I had always pondered on how the creative architect coped with such a demanding practice with so many conflicting requirements and desires. Observing the scene of practice, especially in the tropical region, I was intrigued by the variety of design innovations and creative expressions in architectural works and writings. It varied from traditional derivations to modern interpretations of what architecture should be in the tropical context. At the same time, there were also strange designs that looked like they will work well, but in reality did not perform as expected, for instance in protecting the user from the rain and sun. Four interrelated questions arose. One was how the architect could think and cope with the difficult problem of design in architecture, and the other was how he could get so many ideas, ideologies, innovations, and new creations so quickly in his busy practice. The third was how it was possible for the responsible and sincere architect with sound mind to develop designs that appeared to work, but failed upon closer examinations, and yet the architect continued in his beliefs and went about expounding on his design intentions and ideologies for an appropriate tropical architecture. Equally puzzling was how observers and writers could evaluate such designs, believed that they were successful designs, and wrote well about their performances. The opportunity to examine these curious abilities and quizzical happenings, and how to improve the design thinking skill of the architect came in 1997 as a collaborative research with the Design Knowledge System Research
Cognitive Biases in Design

Centre at the Faculty of Architecture, Delft University of Technology, in the Netherlands.

The research was developed with my thesis adviser Professor Alexander Tzonis, who helped me professionally with expert sharpness. I am privileged and grateful to work with such a dedicated person. I would also like to thank Professor S. J. Doorman for his lessons on related philosophical issues and comments on the thesis. I appreciate the discussions and debates with the colleagues at the Design Knowledge Systems Research Centre, past and present, Xiaodong Li, Nan Fang, Karina Zarzar, Sinan Inanc, and Asaf Friedman. My understanding of tropical architecture broadens with discussions with C. K. Lim of Architect Team 3, K. S. Tay and Patrick Chia of Akitek Tenggara, William Lim of William Lim Associates, G. B. Tang of Tangguanbee Architects, and J. F. Cheng of Design Link. Special thanks to Akitek Tenggara, for allowing the use of one of their building projects, and illustrations as materials for a case study. I am thankful to the colleagues in the National University of Singapore, Milton Tan, and B. L. Ong for their kind suggestions and encouragements. I would like to thank Prof. W. L. Porter, Prof. S. J. Doorman, Prof. J. Kristinsson, A. Prof. K. P. Lam, and Prof. D. Shefer for being on my committee. I am indebted to Liane Lefaivre, and Asaf Friedman for reading and commenting on parts of the manuscript. Merel Miedema for Dutch translation, Janneke Arkesteyn for help in administrative matters, Cherie Bay for proof reading, and Luke Goh and Sims Teo for their moral backings. Special thanks goes to the Delft University of Technology for the hospitality to facilitate me in this research, and the National University of Singapore for the kind grant of leave and financial support. To my wife, children, parents and sisters, I wish to thank them for their love, patience and continuous support. My warmest appreciation to my wife, Chay-Hoong Tan, for being there for me, through thick and thin in this adventurous yet tedious journey.

Joo-Hwa BAY
Delft, 2001
CONTENTS

Abstract vii

Preface and acknowledgement ix

Contents xi

Introduction 1

1. The case of tropical architecture 11

Preliminary case study to understand the pragmatic paradigms, constraints, and problems in design thinking in practice

Some general aspects of tropical architecture 12

Some early discussions about tropical architecture 13

Defining tropical architecture 15

Some aspects of environmental control 17

The practice of tropical architecture in Singapore 22
Cognitive Biases in Design

Traditional examples 22
Modern examples 23
Recent tropical design paradigms 31

Analysing some aspects of practice, overconfidence in thinking, and errors 44

2. Design precedents in tropical architecture 49

Design thinking with the use of precedents as heuristics with analogical, pre-parametric and qualitative means, and problems of biases in tropical architecture

The use of precedents to overcome difficulties in design 50

Design problems cannot be solved by analytical approach alone 52
Precedents are necessary for solving design problems in practice 54
Precedents as analogical means of thinking 56
Precedents as pre-parametric and qualitative means of thinking 57

Precedents and design guidelines for environmental control 60

Limitations of typologies for environmental control 61
Limitations of quantitative analyses for environmental control 62
Limitations of computer simulation with expert advice 65
Design guidelines that are generally suitable for analogical, pre-parametric, and qualitative design thinking

Precedents and heuristic biases in design thinking

3. The problem of cognitive biases

Methodology to study the problem of heuristics and biases in design thinking: With the case of tropical architecture

An interdisciplinary method of investigation
  Basic assumptions and problem statement
  Cognitive theoretical framework
  Descriptive case study approach
  Cognitive experiment

4. Illusions

Illusions related to human judgement and decision-making

Some aspects of illusions in thinking
  General illusions in human perception and conception
  Illusions affecting judgement and decision-making under uncertainty

Heuristics and biases
  Representativeness and the illusion of validity
  Availability and biases due to imaginability
  Other heuristics and biases
  Cognitive biases lead to errors
5. A case study of a specific building project

*Understanding heuristics and biases in design thinking with a specific building project*

**Objectives and method of the case study**
- Objectives of the case study
- Selection criteria of a specific building project for the case study
- Descriptive case study with multiple sources of data collection

**Descriptions of the building, design approach and performances**
- Description of the building project
- Design intention, precedents, and process
- Description of design performances in environmental control
- Building performances related to environmental control on site

**Analysing the findings for heuristics, biases and errors**
- Some observations on the characteristic of the design process
- Precedent entities and properties used as heuristics
- Biases due to representativeness - ‘A’ similar to ‘B’ therefore
- Biases due to availability - ‘A’ is easier to imagine therefore
- Limitations of case study to establish other biases
6. A model of design thinking with heuristic biases

Theoretical model to understand how and why errors of judgement and decision occur in design: In the case of tropical architecture

Elements in the heuristic design process

Cognitive structure in design thinking
- Normative and descriptive thinking
- Representing the structure of thinking
- A kernel of conceptual system
- A framework of architectural knowledge
- Relating the framework of architectural knowledge to the conceptual system
- Learning and remembering precedents

Representing the problem of heuristics and biases in design thinking in the case of tropical architecture
- Model relating to representativeness and illusions of validity
- Model relating to availability and biases due to imaginability
- Beliefs in facts, biases, and rationality

7. Debiasing

A framework for debiasing illusions in design thinking

Various suggestions for debiasing and limitations
- Brief survey of strategies for debiasing
- Evaluations of some strategies of debiasing
Introducing a rebuttal mechanism for debiasing in design thinking

Positive mindset in design thinking
A descriptive thinking model with a rebuttal mechanism
Kernel of Conceptual System with a rebuttal mechanism for debiasing
Criteria for testing the therapeutic model

8. Cognitive experiment

Testing the theoretical therapeutic model for debiasing in design thinking

Experiment set-ups and test results

Objectives of experiment
Test set-ups and procedure for testing biases and debiasing strategies
Summary of results of tests for biases and debiasing

Analysing for biases and effectiveness of debiasing strategies

Testing representativeness biases and debiasing strategies
Testing availability biases and debiasing strategies

Limitations of the experiment
9. Evaluation and conclusion

Summary of the findings, contributions, limitations, and potential extensions and generalisation of thesis

Summary of major ideas in this study
Errors in design judgements and decisions are linked to biases, in the case of tropical architecture

Extensions and generalisations
General applicability to the entire architectural design domain, other design domains, and limitations
Applications, improvements, and future extensions of this research
Applications for practice, pedagogy, and research

Conclusion

Samenvatting
Nederlandse samenvatting van het proefschrift

Appendix A
Illustrations of tropical architecture

Appendix B
Illustrations of bioclimatic design guidelines

Appendix C
Illustrations of a specific building project
INTRODUCTION

This dissertation investigates,

i) How cognitive \textit{biases}\(^1\) (or illusions) may lead to errors in design thinking,

ii) Why architects use architectural precedents\(^2\) as heuristics despite such possible errors, and

iii) Develops a design tool that can overcome this type of errors through the introduction of a \textit{rebuttal} mechanism. The mechanism controls \textit{biases} and improves accuracy in architectural thinking.

'Heuristics' used here are in the sense referred to by Tversky and Kahneman (1982a) and Schon (1983) as thinking relying on the use of intuition, human feel, experience, rules-of-thumb, examples by analogy for judgement and decision making in real life conditions, without normative analysis based on

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\(^1\) Cognitive 'bias' used here is in the sense referred to by Tversky and Kahneman (1982a) and Osherson 1995 as 'illusion' related to certain heuristic used in thinking that leads to error in judgement and decision making. This may not be confused with 'bias' in the sense that 'he has a bias for red', meaning 'he tends to prefer red emotionally or ideologically as a colour or style'. This does not mean that his 'tendency' or 'preference' cannot cause a heuristic \textit{bias}; i.e. if this inclination influences a heuristic in use, a resulting heuristic \textit{bias} can be linked to it.

\(^2\) Precedents, in this study, refer to knowledge that is embodied in examples, types, rules, and principles that the architect refers to inductively and analogically as heuristics to solve difficult design problems like architectural design. This is done with pre-parametric and qualitative ways of thinking, without quantitative calculations. Please refer to Chapter 2 for a detailed discussion on these aspects.
mathematical representation. Tversky and Kahneman (1982a) gave many examples of experts in real-life conditions of practice, who are obliged to use the necessary heuristics to solve various problems in politics, business, and the clinical and legal professions.

George Polya (1973, 113) asserted that human beings are obliged to use 'heuristic reasoning' based on induction and analogy for solving problems when the actual complete solution is uncertain at first. The design problem in practice in a sense is also difficult and uncertain, with incomplete information, limited time and human mental resources. It is not possible to analyse all possible alternative solutions, multiple contingencies and multiple conflicting demands, as doing so will lead to combinatorial explosion. Heuristics are necessary, very powerful, and capable of solving problems with such difficulties.

Payne (et al. 1997, 183) argued that this approach of thinking simplifies the search for solution through a problem space of multiple alternatives efficiently, and that "the use of heuristics often represents intelligent, if not optimal, decision making." However, this may sometimes be affected by cognitive biases, such as the illusion of validity and biases due to imaginability that leads to serious errors in judgement and decision-making (Tversky and Kahneman 1982a).

In the architectural domain, the architect is instrumental in design judgements and decisions that will affect many users, just as the doctor is in

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1 This does not mean that there is no place for normative and quantitative methods. Nishett and Ross (1980, 274) referred to the person in real-life practice as an 'applied scientist' and contrasted it with the pure scientist who uses normative and quantitative methods, where "by contrast, is concerned less with the underlying nature of reality than with the pliability of the real world, less with discovering and understanding new phenomena or higher order regularities than with determining which phenomena or regularities can be used in solving immediate practical problems".

2 Heuristic, used as an adjective, means "serving to discover". For instance, discover by generalisation, specialisation, and analogy an auxiliary problem (Polya 1973, 113, 131), which is more accessible and a step closer to solving the problem.

3 It is noted that for quantifiable problems, many assumptions are also made based on experience to reduce the variables needed for computation in order to avoid combinatorial explosions for practical reasons. In practice it is not practical or possible to consider all alternatives exhaustively.

4 There are many illusions in human thinking, which we will discuss in Chapter 4. Please refer to McClosky (1983) for more discussions on illusions, 'naïve science' and faulty mental models, and Howard Margolis's (1993) Paradigms & barriers: How habits of mind govern scientific beliefs, for more discussions on human thinking and problems in scientific discovery.
the clinical domain. The errors in design judgements and decision-making can have serious implications on the quality of living, sustainability, and have long-term impacts. Firstly *biases* may affect judgement or prediction of design performance for a new design, resulting in designs that do not operate and perform as intended or required. Secondly, *biases* may also affect post-design evaluation and future design thinking. For instance, when an architect observes various completed architectural works on site or from books or magazines, he performs post-design evaluations of how well different designs perform in various conditions, so that he may use them as precedents for future design thinking. If such evaluations are affected by *biases*, then errors can arise. Also if a writer judges completed design works heuristically and reports on the performance of these works with hidden errors, then readers of these reports of designs and performances can be affected in their future design thinking if they used these reports as precedents for design.

With a better understanding of how *biases* affect predictive and post-design judgements, and modelling the problem explicitly with a conceptual system, we can propose a tool for controlling this type of errors. This can be used for improving design training, accuracy architectural publications and educational materials, and design thinking in practice.

**Brief background**

In this study we will examine the problem of cognitive *biases* in the case of tropical architecture\(^7\), particularly in Singapore. An understanding of the design problems in this urban context and climatic environment is relevant to understanding similar design problems in other rapidly growing cities, especially in Asia. The whole issue of designing adequate environment for

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\(^7\) ‘Tropical architecture’ is as defined by Maxwell Fry and Jane Drew (1982) as architecture in the tropical geographical regions. Good tropical design ought to provide adequately for the pragmatic social/cultural needs, the tropical climatic comfort and employ the appropriate means and materials for construction. More elaboration can be found in Chapter 1.
quality of living and working, including convenience, climatic comfort and also sustainability is crucial.

Donald Watson (1991, 134) noted that: "If the genesis of architecture were to incorporate environmental principles to the same extent that it follows Vitruvian precepts then all architecture would be 'environmental architecture'". Many environmentalists like Watson deliberated on the education of morality and the need to incorporate environmental principles in architectural design in the age of ecological crisis. For Watson, the scarcity of environmentally sound design stems from a lack of integration between ecological and architectural principles. All these sound sensible, and it seems reasonable to expect such integration from responsible architects. The contemporary production of tropical architecture should include adequate response to the tropical climate, but is however problematic, with varying degrees of success and inconsistency (examples to be discuss in detail in Chapters 1 and 5). ⑧

This is unlike indigenous architecture, where response to the environment and social/cultural structures was fully integrated with the mode of construction and design expressions, and refined through time. In the modern context, the rapid developments of buildings do not allow enough time for feedback and refinement. The architect depends on whatever precedents he has learned and assumed to be good in performance to help guide his design thinking. Besides current multiplicity of competing demands, limited mental and time resource, low fees also affects design thinking. Low fees aggravate his scarcity of time resource and do not allow him the luxury of employing experts to help him with quantitative calculations and simulations. By using precedent knowledge as heuristics in design thinking, the architect saves considerable resources, and is able to cope and has the opportunity to produce effective and creative designs, but with risks of errors.

We propose that there is a link between cognitive biases and errors in design thinking in the case of tropical architecture.

⑧ Bruckhardt (1992) observed a similar trap in design for ecology. Many award winning and well-featured ecological projects are not as ecological as they were intended or appear.
Problem statement

We assume that the professional architect is honest, responsible and rational\(^9\), neither insane nor a deliberate deceiver, nor ignorant of the advantages of appropriate architectural design. ‘Rational’ here is used in the sense as Simon’s (1969, 1986) definition of ‘bounded rationality’, where it is rational if one solves his problems, not to the extent of a complete maximisation, but sufficient to get by and achieve the goals in life. The architect honestly believes he has judged and decided correctly, and that the design is sound, despite the presence of errors. We propose the following problematic:

The problems of inaccuracy in judgements and decisions in architectural design for the tropical climatic environment, even though the architect\(^10\) is most of the time rational in his daily activities, is linked with heuristic biases. Appropriate refocusing of the mind on opposite outcomes in judgement with a rebuttal mechanism can debias these biases, and thus improve design thinking.

We assume that the designer is will unlikely change from using the power of heuristics for doing his work, to something else, like using quantitative method alone (unless they can be so good as to replace that), or computers alone (unless artificial intelligence matches or surpasses the human mental ability for doing his work). This study limits its scope to studying the use of precedents as heuristics in design thinking with their associated biases as the cause of errors in design. There are other ways of design thinking, and biases are not the only reasons for incidences of design errors. Errors can be attributed to many other factors, including poor education of the architect in the understanding of environmental issues, low fees by non-appreciative clients that limit search for appropriate solutions, outdated building codes

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\(^9\) This is in a similar sense to Cherniak’s (1986) ‘minimal rationality’.

\(^10\) ‘Architect’ here means a designer or a team of designer who designs a building project in the architectural domain.
Cognitive Biases in Design

and regulations, and insufficient details about precedents in reading materials. In a sense they are interrelated and there are overlaps in their effects on design thinking.

Method of investigation

The bottom-up understanding of the case of tropical architecture, studied using the descriptive case study method, will be interpreted top-down with the theory of action, decision theory, and design methods to explain the problem of biases in design thinking. Cognitive theories about heuristics and biases by Tversky and Kahneman (1982a) are used together with knowledge from environmental engineering and architectural theories are employed to understand how errors of design judgements and decisions are made. We will construct a model to represent and account for how the concerns of externality (environment) are inadequately handled in the mind, resulting in seemingly irrational decisions and external pragmatic errors.

Architectural design is diverse in nature and application-oriented, and it is difficult, just to discuss it abstractly. The case study allows us to specify the decision processes, multi-faceted and holistic problem, and focus in detail and depth on the domain problem without loosing applicability (Yin 1993, 1994; Hamel et al. 1993).

We will begin by reviewing tropical architecture in general and specifically in Singapore, as a preliminary case study, in Chapter 1. We will examine the difficulties in practice, including various design paradigms, beliefs and assumptions, and how design judgements and decisions were made with various related problems. (Please see procedure of study below, Figure I-1.)
### Figure I-1 – Procedure of study

<table>
<thead>
<tr>
<th>Procedure of study</th>
<th>Chapter</th>
<th>Description of procedure</th>
</tr>
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<tbody>
<tr>
<td>Preliminary case study</td>
<td>1</td>
<td>Descriptive case study of the practice of tropical design, definition, paradigms and problems</td>
</tr>
<tr>
<td>Bottom-up</td>
<td>2</td>
<td>Analysis of case for the characteristics of design precedents for climatic environmental control, the pre-parametric and qualitative design approach, and the problem of biases</td>
</tr>
<tr>
<td>Problem and methodology</td>
<td>3</td>
<td>Definition and scope of the problematic</td>
</tr>
<tr>
<td>Method of investigation</td>
<td></td>
<td>Description of a proposed interdisciplinary methodology of study: Theoretical framework, case study method and experiment</td>
</tr>
<tr>
<td>Theoretical review</td>
<td>4</td>
<td>Theoretical discussions on perception, illusions and judgement under uncertainty to be used to analyse the following case study</td>
</tr>
<tr>
<td>Top-down / how and why</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A case study</td>
<td>5</td>
<td>Descriptive case study of a specific building design, to know how precedent entities and properties are used</td>
</tr>
<tr>
<td>Bottom-up</td>
<td></td>
<td>Analysis of case with for errors and possible biases linked to these errors</td>
</tr>
<tr>
<td>Theoretical interpretation</td>
<td>6</td>
<td>Descriptive interpretation of theory of action, decision, and design method to case to understand and explain</td>
</tr>
<tr>
<td>Top-down / how and why</td>
<td></td>
<td>Proposal of a theoretical model</td>
</tr>
<tr>
<td>Therapeutic proposal</td>
<td>7</td>
<td>Short prescriptive discussion on strategy for improvement to design judgement and decision-making</td>
</tr>
<tr>
<td>Top-down / what and how</td>
<td></td>
<td>Extension of theoretical model</td>
</tr>
<tr>
<td>Cognitive experiment</td>
<td>8</td>
<td>Experiment to test theoretical model and therapeutic tool for reliability</td>
</tr>
<tr>
<td>Empirical verification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation &amp; conclusion</td>
<td>9</td>
<td>Discussion on general applicability, limitations and improvements. Future applications and extension of study</td>
</tr>
<tr>
<td>Reflections and conclusion</td>
<td></td>
<td></td>
</tr>
</tbody>
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We will then analyse these characteristics in relation to the various aspects of design in general, to be discussed in detail in Chapter 2, in order to state and scope the problematic, with the aim of the development of a tool for improvement, in Chapter 3.

To form a top-down view of the problem, we will discuss various related theories of illusions in human thinking in Chapter 4, for use in discussion in the case study of a specific building project in Chapter 5.

The case study approach will be applied to study a specific building project in detail in Chapter 5, to understand the entities and properties in the precedents used as heuristics for designing climatic environmental controls that resulted in errors. These will be analysed in relation to theories of heuristics and biases from Chapter 4.

With these case study findings, a minimal conceptual system (Tzonis et al. 1978) and a framework for architectural representation (Tzonis 1992) will be used to model a minimal cognitive structure of the heuristic design process and the problem of biases in tropical architecture. These will be discussed in detail in Chapter 6.

From the discussion of general therapeutic strategies in various disciplines, a specific strategy for debiasing will be considered and applied to the model for debiasing design thinking. The creative architect tends to be optimistic in his result orientated design approach, and may be overconfident in his judgement of various outcomes of design performance. A tool for debiasing, by introducing a rebuttal mechanism (based on Toulmin et al. 1984) to refocus the mind on opposite outcomes in judgement, will be discussed in Chapter 7.

The therapeutic tool will then be verified experimentally, with a series of tests, to see the effectiveness of the proposal. The set-up and positive results of the experiment will be discussed in Chapter 8. The findings of this study, general applicability, limitations and suggestions will be discussed in the final chapter, Chapter 9.
Outcomes of the study

The anticipated outcomes and contributions of this study are:

1. A better understanding of design thinking, through a descriptive account of how errors are made, rather than the usual normative approach that focus on idealized models or models of success, especially in the habits of architectural studies. Much efforts and emphases are placed on the discussions of the standards required in environmental design for the comfort and convenience of the user, as well as for sustainability for a world in ecological crisis, and on moral persuasions. It is therefore useful to understand how biases can create irrational persistence of belief in the designer that the design is adequate, even though there are errors. Otherwise, no matter how good the standards or moral persuasions are, there may always be a lack of accuracy in judgement and decision, with consequential errors of performance of various buildings because of biases related to the use of heuristics in design thinking.

2. An interpretation and exploration of tropical design in the domain of architecture in terms of theories in the domain of cognitive science in general, and in particular the theories of biases. An addition to the continuing multi-disciplinary research in design thinking and design knowledge systems, such as the study of precedent analysis in architectural design (Tzonis 1992, Fang 1993), and the resolution of conflicts in beliefs and norms in design (Jeng 1995) at the Design Knowledge System Research Center, Faculty of Architecture, Technological University of Delft, and the study of design thinking and information system (Tan 2000) at the School of Design and Environment, National University of Singapore.  

\footnote{For more information of various related research works, please refer to Internet site: http://www.bk.tudelft.nl/dks and http://www.arch.nus.edu.sg respectively.}
3. An extension of the discourse on judgement and decision-making under uncertainty, heuristics, and biases in the domain of cognitive psychology.

4. An explicit model of the problem. Schon (1983, 49, 61) wrote about the need for the practitioner to ‘reflect’ on his actions in order to avoid errors and improve his work. Arkes (1986, 587) wrote that knowing one has a problem with biases does not help him avoid the effects of biases. The problem remains implicit, as the person still do not know where and how exactly the biases affect his thinking. With the conceptual system and framework for representing architectural knowledge, the chain and structure of thinking can be represented for clearer reflections of the problem, to pinpoint more specifically where and how errors occur.

5. A prescriptive tool for therapy and improving design thinking through debiasing with a rebuttal mechanism, based on the understanding and explicit conceptual model of how errors occur in design thinking in the case of tropical architecture.

6. A set of knowledge on design heuristics and biases that can be referred to by designers in architectural practice, and in the design studio in architectural schools for improving their use of heuristics for design thinking in their projects. The understanding can also be extended to help designers in other areas including interior and industrial design, to improve their design thinking and decision-making. The knowledge can be used to guide the preparation of educational methods and materials in design, and also form the springboard for further research into the various related aspects of design thinking.
CHAPTER 1

THE CASE OF TROPICAL ARCHITECTURE

Preliminary case study to understand the pragmatic paradigms, constraints and problems in design thinking in practice

In the introduction we pointed out that responsible architects ought to integrate environmental concerns in their design and produce building designs that perform adequately for various environmental needs. In this chapter, we will review the case of tropical architecture as a preliminary case study (Yin 1993, 1994; Hamel et al. 1993), in general and specifically in Singapore, to understand the difficulties in practice, including various design paradigms, beliefs and assumptions, and how design judgements and decisions were made with various related problems.

Various writers have discussed the issue of designing and building in the tropical region, and proposed guidelines\(^1\) for arriving at regional\(^2\)

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\(^1\) 'Guidelines' refer to statements or other indications of procedure by which one can determine a course of action, in this case to design for the tropical region.

\(^2\) Regional here is used in the broad sense as to mean "of the region". There is also a particular sense of the use of the terms 'regional' and 'regionalism' in 'critical regionalism' for the context of fast
architecture, responding to the climatic characteristics and related factors, including social-cultural needs, materials and means of building, and aesthetics. A few key examples will be highlighted to form the basis for discussing tropical design in Singapore. We will first discuss in general several international writers’ observations and thoughts for tropical design after the Second World War. From this the term ‘tropical architecture’ will be defined for this study, and the framework will be set up for discussing what appropriate tropical design is. Second, using this framework, we will discuss how architects designed in practice with several important architectural developments in tropical Singapore, especially since Singapore’s self-rule in 1959, and several contemporary paradigms of tropical architecture from the 1980’s onwards. Then we will analyse the case for various characteristics of design in practice such as the difficulties in the design problem, the use of precedents, assumptions made regarding environmental performances, and the associated problems.

Some general aspects of tropical architecture

Though the field of environmental science developed out of the concerns for working and living conditions during the Industrial Revolution (Cowan 1978 217) much of the research and practice concentrated mostly in temperate zones. The interest in the issue of building in the tropical regions grew rapidly only after the Second World War, where many developing nations in the tropical regions received help from the United Nation. In the conference changing developing cities that are influenced by globalisation, and eroding traditions and sense of place. Please refer to Bay (2001) for more discussion on this other aspect.

1 There was the knowledge for adapting colonial buildings to the tropical environment, but not the type discussed for the scale of development by the Building Research Advisory Board (BRAD), and the application of environmental science.
on ‘Housing and building in hot-humid and hot-dry climates’ 1952 organised by the Building Research Advisory Board (BRAB 1953), the Chief of United Nation Housing and Town Planning Section announced that the “big show now is in tropical areas, especially in the Southeast Asian areas”. The conference received presentations from a multi-disciplinary panel, ranging from architectural practitioners, environment scientists to experts from public health departments, which brought their expertise to bear on architectural design in the tropics. The 1950’s onward saw several discussions and publications discussing what ought to be for architectural design in the tropics with multi-faceted concerns. In this section we will discuss the overall understanding of tropical architecture, whether air-conditioned buildings are considered appropriate tropical designs, and the variety of concerns involved in tropical architecture.

Some early discussions about tropical architecture

Referring to the practice of architectural design by Western experts, one of the observations at the BRAB conference, mentioned above, was that many houses had been designed in more or less stereotyped ways to meet a wide variety of climatic regions, and that most designs were based on assumed average conditions rather then the specific local climatic condition (BRAB 1953). Several architects and writers had argued that architectural design ought to differ from one geographical-climatic zone to another.

Fry and Drew (1956) wrote *Tropical architecture in the humid zone* as guidelines for Western architects to design and build in the tropical region, because most of these architects are not aware of the different demands in the tropics. Fry and Drew (1982) in 1964 proposed, in their book, entitled ‘*Tropical architecture in the dry and humid zones*’, thus defining ‘tropical

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4 Among the papers was Olgyay’s (1952) paper on ‘Bioclimatic approach to architecture’.
architecture', that: "There are three main considerations influencing architectural design in the tropics, which it is necessary to distinguish as belonging particularly to the zone. These concern, first, people and their needs; second, climate and its attendant ills; and third, materials and the means of building." They also observed that these concerns were intricately related and had evolved into built-environments with distinct physical characteristics in the indigenous examples of the past.

Similarly, Olgyay and Olgyay (1963, 6-10) had compared various indigenous examples of built environment across the world to "find a remarkable correspondence between special architectural features and certain climatic zones", in their book entitled 'Design with climate; Bioclimatic approach to architectural regionalism'. They referred to various thinkers from Socrates to Le Corbusier concerning this similar observation of the relation between architecture and climate, and the need for differences in design response for different zones. They cited Vitruvius in De Architectura: "For the style of buildings ought manifestly to be different in Egypt and Spain, in Pontus and Rome, and in countries and regions of various characters. For in one part of the earth is oppressed by the sun in its course; in another part the earth is far removed from it; in another it is affected by it at a moderate distance."

Dandy (1963) referred to the guidelines for integrating social-cultural needs and building forms and materials with the tropical climatic concerns as the "grammar of architectural design" for the tropics in his book entitled 'Grammar of architectural design: With special reference to the tropics'.

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5 Their books were intended as guidelines for Western architects of that time. Their earlier book (1956) was Tropical architecture in the humid zone. Maxwell Fry and Jane Drew were practising as architects in the tropics and had written about tropical modern works from the 1930's to the 1960's, drawing lessons from indigenous tropical examples as well as the latest technology in environmental design.

6 Victor Olgyay and Aladar Olgyay were practising architects as well as researchers and writers on the multi-disciplinary relationship of climate, biology, and technology in achieving architecture of comfort and aesthetic delight.

7 As in Olgyay and Olgyay (1963) referring to Vitruvius. DeArchitecture. Book VI. Chapter 1. Translated by Frank Granger (Ariba), 1934.
1. The Case of Tropical Architecture

Olgay and Olgay (1957, 5) discussed how architectural design must be judged: “Man, with his intricate physical and emotional needs, remains the module – the central measure – in all approaches. The success of every design must be judged by its total effect on the human environment”. And by this they were referring to the physical comfort of the occupant in a modern building and the aesthetic delight in seeing a modern architectural expression based on climatic control as “a more positive foundation for the play of emotional expressions”.8

Defining tropical architecture

From the above discussions, three main broad aspects of tropical architecture can be identified. These three interrelated aspects are:

1. Regional expression - as a result of responding to needs related to the tropical region in aspects 2 and 3 below,
2. Climatic comfort and convenience for social-cultural requirements, and
3. Materials and means of building - appropriate to the tropical zone.

The success of the design as tropical architecture is measured according to the appropriateness of the synthesis of these aspects in the hot and humid environment in the context of Singapore. The terms ‘tropical architecture’ and ‘tropical design’ are used in this study interchangeably in the largest sense of the words. Any architectural issue relating to the three aspects above at various physical scales from landscape, urban morphology, individual building down to building elements and components will be

8 Olgay and Olgay (1957) concentrated mainly on the importance and possibilities of solar control and shading devices in this book.
included as tropical issues, as long as it involves or is related to the tropical climate that has implication on the architecture.

*Regional expression*

The regional expression or a ‘grammar’ as referred to in Dandy (1963) is a result of designing with considerations for the climatic comfort and convenience for social and cultural requirements and the use of appropriate materials and means of building.

*Climatic comfort and convenience for social and cultural needs*

Social and cultural factors include the lifestyle, the way spaces are used and occupied, security and movement of people, and the symbolic meanings including traditional/religious forms and motifs. The traditional/religious and climatic forms for various social/cultural needs are integrated, as in the roof form, courtyards, screens or trellis for instance. In the modern context it will be the integration of the needs for business practices, for instance in office buildings with the appropriate corporate image.\(^9\)

*Materials and means of building*

Material considerations will include the selection of suitable materials for the climatic condition, the cost factor, availability of materials, and durability (Lippsmeier 1980). The availability of certain natural timber, for instance, in a specific location is also related to the climatic conditions that support the growth of certain trees. Considerations for materials and means of building

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\(^9\) In the modern context, an economical angle is added onto the requirement in that the development must succeed as an investment, it must work well for people and be marketable.
will also include varied factors including windstorms, cloudburst and flooding, biological elements, structural systems and constructional methods. The choice of paint material to be use, for instance, is preferably one that will avoid the harmful effects of fungus in hot and humid areas.

Some aspects of environmental control

Environmental control in this study refers to the required control of various factors for the immediate needs of convenience and physiological comfort of the occupant of a building, generated by, or related to climatic conditions. Environmental design in the wider sense that falls within the responsibility of the architect, also refers to the design for sustainability in the long term, expressed in terms of low life-cycle energy resource consumption and impact on the overall ecology of the earth (Hyde 2000, 47). We limit our discussion in this study to only the aspects of sustainability that is related to environmental control for comfort and convenience of the occupant of a building. It is argued that ‘climatic responsive design’ solutions with appropriate building orientation, building configuration and building fabric design that take into consideration various climatic concerns, will reduce the dependency on mechanical means of environmental control for comfort and use less energy resources, and is therefore considered part of sustainable

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10 Relevance of appropriate constructional method discussed by Fry and Drew (1982), and Lippmeier (1980) also includes the type of labour available for building in developing countries. More examples of guidelines for building constructional issues: Fullerton (1977, 1978, 1979), Building construction in warm climates.


12 Sustainability in its larger sense is a process that involves many factors that are outside the discussion of this study. Edwards and Turrent in their book (2000) for example, described sustainability as a process involving factors including the conservation of natural resources, re-use of manmade products, maintaining ecology, equity between generations and classes of people, and provision for health, safety and society, in the planning and design of new environments for people. For more information on sustainability, please refer also to e.g. Watson (1991, 1995), and Steele (1997).
architecture (Hyde 2000, 53). In this study we can see that environmental control is part and parcel of tropical architecture as defined above, and that a desirable environmental design is one that provides for comfort and convenience for the occupant of the building, and minimise energy consumption, by being responsive to the climate with appropriate building orientation, building configuration and building fabric design.

The physical factors in relation to the tropical climate that need to be considered in environmental control in tropical architecture, (identified by e.g. Fry and Drew 1982; Olgyay and Olgyay 1963; Lippsmeier 1980; Koenigsberger et al. 1974), include:

1. Solar radiation and sun path,
2. Daylighting and glare,
3. Temperature and temperature change,
4. Precipitation (rain),
5. Humidity,
6. Ventilation, and
7. Noise and air pollution.

In the urban context of fast developing cities, these will also include noise pollution in the congested areas, where a design with lots of openings to encourage cross-ventilation will also invite noise and air pollution. Fry and Drew (1982) also identified the problem of mosquitoes, termites and various pest control measures required in the hot and humid climatic areas, because some of these insects and pests can cause much discomfort and inconvenience to occupants, and also damage to furniture and buildings.

In the control of rain, this may be in the form of a roof or a covered walkway of certain proportion to provide the protection for him to move

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13 The use of appropriate building methods and materials will also reduce the energy use in production and construction, and the harmful impact to the earth’s environment in the long run, and will also be considered ecological sustainable approaches, also discussed by Hyde (2000).
with comfort and convenience from on part of the city to another in the tropical rain. For the control of heat for comfort, it can vary from providing a simple large roof over the head, while allowing cross-ventilation from the sides to keep the occupant cool, or to the use of an air-conditioner system in an enclosed space.

**Thermal comfort**

One of the earlier quantitative approach for determining human thermal comfort was first proposed by Victor Olgyay (1952, 13-23) in his paper, *Bioclimatic approach to architecture* presented in 1952 at the BRAB (1953) conference on *Housing and building in hot-humid and hot-dry climates*. The thermal comfort level for a human user in an interior of a building had been determined by testing human subjects in controlled environments with four varying environmental factors, namely air temperature, radiation, air movement and relative humidity, that interact with the human body metabolism, based on the theoretical representation of the relationships of these factors (please see Appendix B, Figure B-1). The responses of these subjects wearing certain set of clothing were tabulated against the varying environmental factors to produce a *bioclimatic* chart that showed the range of conditions of certain temperature, radiation, air-movement and humidity when subjects experienced thermal comfort; where this range was called the comfort zone (please see Appendix B, Figure B-2). ¹⁴

Refinements have been made by later researchers on the method, assumptions, and parameters for the determination of thermal comfort levels (e.g. Fanger 1970; Taffe 1997). According to Fanger (1970), the most

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¹⁴ Various systems similar to the bioclimatic system have also been developed, and one example is the Equatorial Comfort Index (E.C.I.) system developed by C. G. Webb for Singapore in 1960. For more information of these systems, and other parametric design guidelines and indicators for the control of lighting level, noise level, etc, please refer to e.g. Koenigsberger et al. (1974).
important variables that have a combined thermal effect on the human body, and therefore influence the condition of thermal comfort are:

1. Activity level (heat production in the body),
2. Thermal resistance of the clothing (clo-value),
3. Air temperature,
4. Mean radiant temperature,
5. Relative air velocity,
6. Water vapour pressure in ambient air.

The use of air-conditioners, mechanical fans or ventilators to control various environmental factors above for thermal comfort will be considered 'active' approaches requiring the direct consumption of energy to operate. 'Passive' approaches will be those that do not require electro-mechanical energy to control the climatic factors for comfort. Passive systems include orientating windows away from the direct sunray where possible, providing building elements such as louvers to shade direct and diffused solar radiation, openings to encourage ventilation, suitable planting of vegetation, and so on to keep the interior spaces from overheating. It is of course advantageous to save resources where possible and have a combination of both, with built-in flexibility to control and vary these combinations by the user for maximum comfort as well as minimise energy consumption.

Active and passive means of environmental control

Here, some clarification is necessary as to whether the air-conditioned buildings are part and parcel of tropical architecture. Banham (1969) in his book, *The architecture of the well-tempered environment*, observed that excess humidity in the tropical atmosphere could only be effectively removed by mechanical means. Fry and Drew (1982) described air-
conditioning as one of the effective means employed in the modulation of the hot and humid tropical climatic environment. In this same vein, Lee Kuan Yew (K. Y. Lee), Senior Minister of Singapore hailed the air-conditioner as the most influential innovation of the millennium because it has changed the lives of people in the tropical regions, and allowed businesses to operate efficiently. Lee (1999) stated, “Before the air-con, mental concentration and with it the quality of work deteriorated as the day got hotter and more humid.”

Indeed the problem of air-conditioning, in the context of Singapore, lies not in the fact that it is not an appropriate tropical system for climatic environmental control, but that it consumes electrical energy and does not seem to make use of the natural tropical resources, like the wind for cooling in the case of the indigenous tropical buildings in the past. However, the thermal discomfort owing to the humidity problem cannot be effectively eradicated by cross-ventilation all year round. Coupled with this is the noise and air pollution problem in the congested city. Considering the economic-social-cultural need, the climatic, and the urban condition of Singapore, the air-conditioner has proven to be a sensible tropical device for providing the necessary comfort and convenience.

In various cases, ‘active’ means, with mechanical systems, have also been effectively combined with ‘passive’ means of keeping cool, including sun-shading devices, wind buffers, sky-courts and planting to save whatever running cost possible. Yeang (e.g. 1994, 1997) has developed various ‘guiding principles’ for the bio-climatically considered skyscraper, balancing the ‘active’ and ‘passive’ system for environmental control and energy conservation. It is a struggle or balance between environmental control by means of the design of the building fabric and form, and the reliance on

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15 At the moment, air-conditioners are run with electrical energy from fossil fuels. But soon when alternative sources of energy, including solar energy, are employed, there will be less of a problem with regards to energy consumption. There is also a counter argument that air-conditioners preserve building materials better and prolong the life of the building, which translated to energy is also a saving. This matter goes beyond the discussion of this dissertation.
direct energy means for climatic modulation. Air-conditioned buildings can therefore be considered as part of tropical architecture.

The practice of tropical architecture in Singapore

In this last section we discussed the broad understanding of tropical architecture as the synthesis of three aspects identified above, namely the regional expression, the climatic comfort and convenience for social and cultural needs provided for via ‘passive’ or ‘active’ systems, or a combination of both systems, and the use of appropriate materials and means of building. In this section we will describe several examples of tropical architecture in Singapore, so that we can appreciate and understand the difficulties of the practicing architects with their struggles in designs these multiple criteria. This section will be descriptive. It will form the material for analysis that follows in the last section of this chapter, to examine some aspects of the characteristics of design in practice such as the difficulties of the design problem, the use of precedents as heuristics for design thinking without the use of quantitative calculations and simulations. We will examine the assumptions made regarding environmental performances, and the errors.

Traditional examples

The traditional native architecture of the region of Singapore and Malaysia was typified by indigenous houses on timber-stilt structures carrying large roof with great overhangs and porous walls or minimum walls for maximum
ventilation. Since 1819, the British started to build colonial bungalows with European constructional methods and materials heuristically adapted to the local climate in Singapore. The colonial bungalows were hybrids of the European style and the indigenous style of the region, emulating the time tested climatic performance of indigenous traditional forms (please see Appendix A, Figures A-1 and A-2). The streets in Singapore were characterised by *shophouses*. With continuous covered walkways, called *five-foot-ways*, they provided continuous shade and protection from the sun and rain through large parts of the city (please see Appendix A, Figure A-3). The shophouses were ventilated via internal courtyards and with ‘jacked-roofs’ at the ridge of the roofs. There were also other colonial building types including institutions and warehouses in European styles adapted to the local climate. The colonial way of building continued up to the end of 1950’s, although the influence of the modern movement had begun to appear in Singapore through the British Public Works Department and some private architects trained in the West.

**Modern examples**

In 1937, inspired by contemporary European glass architecture, the Public Works Department designed and built the Singapore Kallang Airport Terminal Building as one of the first of these new generation of buildings (please see photograph in Appendix A, Figure A-4). Its way of adapting to

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16 The Malay House refers to the indigenous house typology common to the region of Malaysia and Singapore. See *The Malay house* (J. Y. Lim 1987) for more information.

17 The colonial bungalow in Singapore was also referred to as the Singapore house in *The Singapore house* (K. L. Lee 1988); and in *The Singapore house and residential life* (Edwards 1990).

18 The provision of *five-foot-ways* for the *shophouses* was a tropical urban strategy implemented for Singapore by Sir Stamford Raffles, examples in *Colonial architecture and architects of Georgetown (Penang) and Singapore* (S. H. Lim 1990), and *Pastel portraits* (Gretchen 1984).

19 Most of this buildings display European Styles including the Pulladian style on the facades (S. H. Lim 1990).

20 See ‘Architectural development in Singapore’ (Seow 1973) for more examples.
the tropical climate was by providing large pronounced horizontal fins over the large areas of horizontal glass facades, offering great expense of shelter from the sun and rain. After the Second World War, Ng Keng Siang (K. S. Ng), one of the first London trained Singapore architects, designed the tallest high-rise building in Singapore’s business district in 1954, namely the Asia (Insurance) Building (please see photograph in Appendix A, Figure A-5). The architect wanted to demonstrate that the local architect could also produce distinctive designs compared to European architects, and strove to achieve this by adapting the facade design to the local climate with articulated horizontal shading strips.

The shift away from colonial tropical architecture and its replacement with a modern tropical architecture became more widespread during the post-colonial period. From 1959 when Singapore had its first self-government, the energetic newly formed regime had the vision to build a metropolis with a people of diverse cultures. Singapore wanted to move forward, throw off its colonial burden, and employ the best of technological know-how from the West with all its potential for rapid development with a cosmopolitan image (Chua 1989). The dawn of Singapore’s nation building saw several major modern architectural endeavours. These include the Singapore Conference Hall and Trade Union House (a very important public building), the Malaysia Singapore Airways Building (the prototype non-colonial, high-rise commercial building in Singapore’s main business street), the People’s Park Complex (the first high-rise complex with high-density mixed-development of housing and shopping complex) and the Woh Hup complex (the experimentation of urban architecture for the new tropical Asian city).

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21 ibid.
22 ibid. There were other examples of works by PWD and private architects of that period in tropical Singapore.
23 The author has selected this few notable pioneer works as examples for discussion after surveying: The Singapore Institute of Architects (SIA) early journals, Rumah and SIA Journals (from 1959), Seow (1973) and Gan et al. (1981).
A modern civic building for the tropics

The Singapore Conference Hall and Trade Union House, completed in 1965, was based on the winning design of an architectural competition in 1962 (please see photograph in Appendix A, Figure A-6). It was won by the Malayan Architects Co-partnership, which consisted of Lim Chong Keat (C. K. Lim), Chen Voon Fee (V. F. Chen) and William Lim (W. Lim) as partners.\textsuperscript{24} Its symbolic importance was great. It was felt as capturing the spirit of the time. As a modern tropical building, it stood proudly in the midst of the old business streetscape in Shenton Way, Singapore's main business street, which had been dominated by colonial style office buildings. Tay Kheng Soon (K. S. Tay), one of the architects who have worked with Malayan Architects Co-partnership at that time\textsuperscript{25}, reports that then Prime Minister Lee Kuan Yew (K. Y. Lee) saw it as a symbol of the new national pride. Tay also reports that Lee in his opening speech referred to the quality of design and execution as proof that "the people have the verve, the capacity and the pride in performance"\textsuperscript{26}. The Minister for Culture and Social Affairs also celebrated the success with this message: "Much effort has gone into this project and now this building asserts itself as an index of the dignity of labour in Singapore"\textsuperscript{27}

In modern geometric composition, the building offered the state-of-the-art conference hall, research centre, and administrative facilities, which were air-conditioned. The central lobby/exhibition concourse to the respective

\textsuperscript{24} Author's discussion with C. K. Lim, Singapore, 1999; C. K. Lim, V. F. Chen, and W. Lim were partners of Malayan Architects Co-partnership from 1961 to 1965; according to C. K. Lim, he and Chen were the key architects involved in the design of the project.

\textsuperscript{25} Author's discussion with K. S. Tay, Singapore, 1999; Tay was an ex-student of C. K. Lim at the Singapore Polytechnic, and was working with Malayan Architects Co-partnership while this project was being designed and built.

\textsuperscript{26} Ibid. K. S. Tay recollected the optimistic atmosphere of the opening speech for the building by K. Y. Lee who was then the Prime Minister of Singapore.

\textsuperscript{27} Message was by the Minister for Culture and Social Affairs in Ministry of Culture and Social Affairs (1965) in the souvenir brochure for the opening of the building on 15 October 1965.
facilities enjoyed cross-ventilation with the prevailing sea breeze blowing through the carefully designed gaps in the full height louvered glass windows. Wind was allowed to enter the building and escape at the highest point of the grand interior atrium without allowing rainwater from entering.  

The rectangular aluminium sunscreens together with the cantilevered roofs formed the large canopy-like expression of shadiness. The interior timber stripe finishes were from this tropical region. The whole exterior form, interior spaces and landscape design were treated as part of the total architectural concept with no reference to colonial forms or styles. C. K. Lim explained that the design approach was not one of derivative-regional-identity, but of integrity. It was an aesthetic based on the Modern language of the Modern Masters and the guidelines for designing appropriate tropical architecture by Olgyay and Olgyay (1963), and Fry and Drew (1982).

_A prototype modern corporate office building for the tropics_

With the same state-of-the-art technology and architectural language, Lim started designing the first post-colonial corporate high-rise tropical building in the Singapore business district in 1965, called the Malaysia Singapore Airway Building (please see photograph in Appendix A, Figure A-7). Completed in 1969, it stood then as the tallest building in Shenton Way. Its

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28 Author’s discussion with C. K. Lim, Singapore, 1999; Lim was confident that the naturally ventilated lobby and exhibition concourse works well and need not be air-conditioned, in the present renovation work on the building by another architect. He said, “There is very little change to the micro-climate, nor the level of pollution”, and therefore doubted the necessity for a modification.

29 Author’s discussion with C. K. Lim, Singapore, 1999: the discussions on tropical architecture by Olgyay and Olgyay, and Fry and Drew, discussed in the previous section, were popular at that time. Though the bioclimatic design guidelines were referred to, no calculations were employed, as the graphical guidelines in the book were used to guide the heuristic design thinking process. The air-conditioning and acoustic requirements were of course computed by the relevant experts, just as the structural designs.

30 The Malaysia Singapore Airline Building was later called the Singapore Airline Building. Unfortunately this building was demolished to make way for bigger facilities with higher plot ratios. Today, the Singapore Airline Building is a pristine glass tower sitting on the same site.
elegant tripartite tower rested on a horizontal podium below, which cantilevered out to shade the walkway along the main street. It was equipped with an auditorium, a landscaped podium roof for recreational purposes away from the buzzing street and multi-storey car-parking facilities. The glazed facades were sealed for air-conditioning and for great sea views, and they were protected from the sun and glare with lace-like U-shape aluminium shading devices that formed a rhythmic pattern. It is important to understand, that being the first modern high-rise corporate building for a new nation, it had to satisfy multiple criteria including the corporate image, user needs, the urban fit, adequate technology and the unique environmental problem, which had few precedents except Western models, which were adapted to local climatic conditions based on guidelines of climatic design discussed by Olgyay and Olgyay (1963), and Fry and Drew (1982), as in the previous project discussed above. When it was completed, it was considered an exemplary prototype for the development of other corporate commercial buildings for the whole business district.\footnote{This was the prototype for the intensive high-rise office developments that was to follow along Singapore’s business district (Chua 1989).}

\textit{A prototype mix-development for housing and shopping}

While the Malaysia Singapore Airway Building was a prototype for office buildings, the People’s Park Complex was a prototype for mixed-development of shopping and residential dwellings (please see photograph in Appendix A, Figure A-8). It was conceived in 1967 and completed in 1970 by Design Partnership, formed by W. Lim, Koh Seow Chuan (K. S. Chuan) and K. S. Tay\footnote{W. Lim, K. S. Koh, and K. S. Tay formed Design Partnership in 1966. Prior to that, W. Lim and K. S. Tay were practising with C. K. Lim.}. The site had previously been occupied by a well-known open-air-night-market in Chinatown, known as People’s Park. The market
was destroyed by fire and the site was subsequently selected as one of the first land sales in 1967 for urban renewal. It was a challenge for the architects to provide a modern solution to accommodate the lost city life and culture of shopping and dining in informal street settings.\textsuperscript{33}

According to Tay, shopping spaces in those days were in the form of streets or malls and not in complexes. The precedent for a shopping centre that matched the scale and complexity of the People’s Park Complex was difficult to find. One of the largest shopping centres was called Ala Moana Center completed in 1959 in Honolulu, in the centre of Hawaii.\textsuperscript{34} It was a huge and long two-storey high complex with large department stores at two ends acting as anchor tenants, connected by a long shopping mall stringed with smaller shops. This horizontally sprawling example however was unsuitable for land scarce Singapore. Drawing on the discourse in urban architecture of the Metabolist, the concept of a vertically stacked model was adopted for the site.\textsuperscript{35}

The idea of connectivity in the city was an important factor in the design of the People’s Park Complex, ensuring that people could flow through conveniently and comfortably from various points and levels of the site. Six storeys of car-parking areas were linked directly into the shopping and atrium area so that people could shop at upper levels. These corridors or streets of activities and interaction were housed in a huge naturally ventilated atrium that provided maximum visibility of shops and were cooled (heuristically assumed to be effective) by the spill over cool air from the

\textsuperscript{33} Author’s discussion with W. Lim, Singapore, 1999; Although the provision of a modern solution to recapture the lost city life and culture of shopping and dining in informal street settings was the key challenge, the consideration for comfort and convenience of movement was also important.

\textsuperscript{34} Author’s discussion with K. S. Tay, Singapore, 1999: the Ala Moana Center was essentially a huge horizontal shopping mall.

\textsuperscript{35} Author’s discussion with W. Lim and K. S. Tay separately, 1999: Lim and Tay were closely following the architectural discourse of Team X and their key correspondence was Kenzo Tange. They had the opportunity to discuss the ideas of Metabolism and Fumiko Maki, and the idea of the ‘City Room’ – urban nodes of energetic human movement and activities. Lim and Tay had earlier discussions with Rem Koolhaas who has written more details on this subject in Koolhaas et al. (1995).
numerous air-conditioned shops. The budget did not allow for air-conditioning the atrium. Mechanical ventilators instead were designed to help extract the warm air. The high-rise apartment tower above the shopping podium was designed such that there is cross-ventilation for every unit of flat, and there was a roof deck over the podium intended for communal activities.

Both Tay and Lim recollected that the complex was a success. A study on visitor volumes, carried out by Design Partnership, showed that 1 million people visited People’s Park Complex in the first month of its opening in October 1970, out a total population of 2.5 million for Singapore at that time. Moreover the atrium was a popular social space for holding exhibitions and cultural shows. The People’s Park Complex performed so well that Design Partnership was awarded many more commissions for shopping cum residential complexes. Among these was the Woh Hup Complex, allowing for further experimentation.

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36 Author’s discussion with K. S. Tay, Singapore, 1999: according to Tay, shoppers could enjoy the cool air from the air-conditioned shops if they felt warm. The mechanical fans were also not installed at completion of the building because of the tight budget. Tay was sure that natural ventilation alone would be inadequate. Business however was so successful that the owners of the building decided to air-condition the building several years later and boxed in all openings with glass panels and doors, destroying much of the concept of connectivity and flow of spaces.

37 There were other examples of high-density housing as in the public housing that have similar considerations and design approaches of cross ventilation for every apartment units. This practice is upheld for every public housing development till today, which in total comprise of more than 85% of dwelling units for the Singapore’s population.

38 Author’s discussion with K. S. Tay, Singapore, 1999: there was however not enough budget for landscaping the roof in the final execution.

39 Author’s discussion with W. Lim and K. S. Tay separately, 1999: Both Lim and Tay recounted the amazing results of the survey.

40 The Woh Hup Complex is today known as the Golden Mile Complex, along Beach Road, Singapore.
A concept of the urban connector for a new Asian tropical city

Like the People’s Park Complex, Woh Hup Complex, completed in 1973, also has a shopping atrium, a residential block above the shopping complex, and a roof deck (please see photograph in Appendix A, Figure A-9). There was also a separate landscaped roof garden with a swimming pool for the residents. The residential tower block was designed so that each apartment unit would have cross-ventilation, especially catching the sea breeze. The block was terraced so as to give each apartment unit a tropical garden open to the sky, and at the same time provide a large sheltered communal space below the whole residential block. These were all judged and decided without the aid of quantitative calculations and simulations. According to W. Lim, K. S. Tay explored the idea of how the multiplication of blocks similar to the Woh Hup Complex along the urban streets could serve as connectors throughout the tropical city. That in theory formed the basis for a future cityscape of inter-connected internal cool spaces as well as the external sheltered urban and communal spaces, serving as platforms for mass rapid transit stations, bus stops, and activity nodes (please see photograph in Appendix A, Figure A-10). Here the model of adequate shade and connectivity was assumed workable and applied in a large scale. It was published in Singapore Planning and Urban Research (SPUR) group publication as a possible solution for the future tropical Asian city.

Looking back to this period, these buildings were daring experiments in the tropical urban context. The Singapore Conference Hall and Trade Union House, the Malaysia Singapore Airline Building, the People’s Park Complex

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41 Author’s discussion with W. Lim, Singapore, 1999: K. S. Tay made multiple copies of drawings of Woh Hup Complex and laid them out as city blocks linked together as an experiment for a new tropical urbanscape.

42 From 1965, W. Lim and K. S. Tay were among the key advocates for generating discussion and research into the future of tropical Asian cities, with unique cultural and community needs. The multi-disciplinary research group called Singapore Planning and Urban Research (SPUR) group produced 2 publications: SPUR 65-67 and SPUR 68-71. More of this is covered in the Author’s
and Woh Hup Complex were great examples of attempts at an architecture to suit the people and the climate with new and changing technologies. However many banal looking buildings lacking critical relationship to place and environment also appeared. Like many rapid growing cities in the region, the skyline of Singapore was marked with anonymous business towers. Growing tired of the globalising effect, some have welcomed historicist references as the alternative; hoping to give saving character to buildings in the 1980’s and 1990’s. Without appropriate understanding and design strategy, historicist reference to European or regional styles can result in kitsch. In the face of losing relevancy and regional character, several concerned Singapore architects and writers have discussed ways to achieve architecture that is appropriate to the region.

Recent tropical design paradigms

This section discusses three tropical architectural design paradigms of differing emphasis, design processes and meanings of the end products (regional expressions) in the context of the contemporary tropical urban Singapore, from the 1980’s. These three paradigms represent three distinct and extreme positions. All the three paradigms seek to achieve recognisable characters in the architecture that belong to the tropical region in and around Singapore, and distinguish it from architecture of the other climatic zones of the world. These paradigms have varying emphasis on the language, the ‘look’ of the tropical buildings, with varying emphasis and assumptions on climatic comfort adequacy.

The first paradigm is based on environmental issues as a foundation, to develop an appropriate tropical language. The second is founded on


43 See some discussions on these paradigms in the issue of regionalism (Bay 1998b, 2001)
tradition-based forms. The third is what we will call a “New Screen and Louver Kitsch” based on stereotype forms of tropical architecture. These paradigms are likely to be universally applicable to other tropical Asian cities undergoing rapid development and globalisation. Issues discussed include the current struggles with globalisation, moving forward, preserving memories, hybridisation of styles and kitsch.

First each paradigm will be described. Then each paradigm will be discussed based on the three main aspects of tropical architecture set up in the beginning of this essay, namely the architectural regional expression, the climatic comfort and convenience for social and cultural requirements, and the materials and means of building. Their nature, conflicts, and problems will be discussed in the analysis section of this chapter.

**The “Line, Edge and Shade” paradigm**

Recently K. S. Tay has argued for an urban architecture that is ecologically responsive and has criticised the conditions of practice and academia saying: "Architecture journals and schools everywhere concentrated on ‘difference’ and style. They seem to withdraw from engagement with real environmental issues. This seems strange when architecture and city planning have always been totally interconnected. As architects today shun the connection, they are reduced to styling and theorising" (Tay 1994). Tay thinks that design should be forward-looking, non-nostalgic and there should be no regression with poor copies of styles from the past, but rather emulate the principles of environmental control from traditional designs.\(^{44}\) Tay (1990a) refers to the local kitsch designs as ‘Obiang’ in his newspaper article commenting on the bad taste displayed in many houses around Singapore, which imitates all

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\(^{44}\) Author's discussion with K. S. Tay, Singapore, 1997: it is good to learn principles employed in traditional architecture.
kinds of traditional or 'Greco-Roman' styles.45 And he believes that "One of the principal issues of designing in the tropics is the discovery of a design language of line, edge, mesh and shade rather than an architecture of plane, volume, solid and void. An unlearning process is involved, given the dominance of European architecture which forms the substance of the training of architects over the past 200 years".46

Tay (1990b, 40) in his paper, entitled 'The architectural aesthetic of tropicality', has noted the hegemony of the box aesthetics of modern buildings with the development and application of weather-tight enclosing curtain wall system during the 30's in the West, and has argued that the aesthetic approach ought to be different for the tropical region. As an alternative to the aesthetic of the "scaleless bland box", he proposed the followings (op. cit., 41):

i) The roof should be the main feature as opposed to the wall, where the roof will provide the shade, shelter, shadow, and profile, allowing for a play of gradations and transitions of shade and shadow and a "'fuzzy' wall with the tremendous possibilities in integrating use functions and variations into it".

ii) "The building section takes precedent over the plan as the generator of building form and as the basis of design thinking. The tendency of the elevations of a building to be an extrusion of the plan is dispelled once the roof predominates and the walls are merely partial enclosures, no longer required to be the absolute limit of the interior space of the building." The external surface of the building can be a space resource with interpenetrating layers between the inside and outside space.

45 See 'Wah so Obiang one' in the Straits Times (Tay 1990a). 'Obiang' is a colloquial meaning kitsch, poor taste, cheap, imitative or plastic. 'Wah so Obiang one' can be rendered approximately as 'Oh, so bad taste'.
46 As quoted in the introduction in Powell (1997)
iii) In relation to surface treatment, the layers may be conceived as “meshes or fretwork patterns and trellis screens”, “producing a totally different architecture from that of the planar wall”.

iv) Profile and edge are also important formal aspects to address how a "building engages the often cloudy sky in soft diffused light” as opposed to the strong contrasting Mediterranean sky.

Based on Tay's proposal above on the use of 'line, edge, and shade', and the title of the book about his firm's works (Powell 1997), we will refer to this paradigm as the "Line, Edge and Shade" paradigm in this study.

One of the notable examples of work employing this tropical design language is the Bishan Institute of Technical Education (please see photograph in Appendix A, Figure A-11). His firm, Akitek Tenggara II, won the design competition for this project in 1989 and completed it in 1993. Large curved roofs were designed and intended for sheltering the outer façade from rain, give shade from the sun and cast various shades of shadows. The large horizontal louvers on incline plane shade the windows and are generously spaced, intended to allow wind to flow through the windows of the classrooms that are predominantly naturally ventilated. There is no direct derivation of traditional forms or styles, but only reference analogically to the examples and principles of rain protection, sun shading and ventilation of the traditional architecture, and all the materials and method of construction are modern. The prominent lines and edges of the buildings, the image of permeability and transparency, and the strong shadows together form a distinct character, an architectural expression noticeably different from the "scaleless bland box” Tay talks about.

The diagram, in Figure 1-1, can serve as an encapsulation of this tropical design paradigm. The regional expression is based on a language founded on the tropical climatic considerations. The expression is to be directly related or derived through the provision of climatic comfort and convenience for the
specific social and cultural needs. The materials and means of building are modern and non-traditional.

Figure 1-1
A diagram for the “Line, Edge and Shade” paradigm

![Diagram showing regional expression, climatic comfort and convenience, and materials and means of building]

Regional expression (architectural language based on response to the tropical climate)

Climatic comfort and convenience (starting point)

Materials and means of building (modern, non-traditional)

This paradigm is especially applicable to high-rise high-density development where the old way of extruding the plan multi-storeys and be replaced with one where the vertical planes can be varied and layered with various possibilities of usage and resultant characters. While this “Line, Edge and Shade” paradigm affords functional and forward-looking expressions; the buildings tend to be cold looking and lack affinity with rich cultural pasts and geographical-material of the tropical context. Most new manufactured materials tend to be harsh and are not as effective as traditional materials like wood and stone in handling heat and glare. They also lack the character of some older natural materials that has been associated with the charm and visual comfort in indigenous regional architecture, architecture that mellow well with time.
The “Tradition-based” paradigm

Contrary to the above approach, Tan Hock Beng (H. B. Tan 1994) has argued for a need to evoke traditions in the tropical Asian architecture and proposed that there is an authentic way of doing tradition-based design to ensure new production of rich tropical architecture for this region.\footnote{H. B. Tan is a writer and a practising Architect who proposed a way of doing tropical Asian architecture.} He has also criticised the prevalent “Neo-Greco-Kitsch” and careless copying of traditional images, and wrote: “In the face of a self-indulgent architecture of Postmodernism and the reductive universality of Modern architecture, these rapidly developing countries have begun to look at (traditional) built forms as an expression of their own aspirations and identities” (op. cit.). He calls for a true understanding of the traditional large pitch roof form, planning for cross-ventilation, in-between realms and courtyard, traditional openings, tropical materials, water and landscape, and the appropriate application of such elements so as to ensure the integration with nature and a poetic expression of tradition.

To avoid the homogenising effect of globalisation, and to preserve the richness of local traditions, Lim and Tan (1998) proposed the following four strategies in different chapters of their book entitled ‘Contemporary vernacular: Evoking traditions in Asian architecture’:

i) “Reinvigorating Tradition” – “evoking the vernacular” by way of “a genuine reinvigoration of traditional craft wisdom” and not being “tacky versions of skin-deep treatments of indigenous archetypes”. Suggesting that a genuine admiration for the vernacular through a genuine reinvigoration will result “in the perpetuation of an
architectural language that assumes the status of authenticity through ensuring a perceived historical continuity”.

ii) “Reinventing Tradition” – “the search for new paradigms” by way of a hybridisation in the same sense as how the British colonials were “reinventing tradition” by building colonial bungalows drawing lessons from the Malay house.

iii) “Extending Tradition” – “using the vernacular in a modified manner” as in Geoffrey Bawa’s “use of his country’s vernacular structures and its tradition of inherited craftsmanship” for a contemporary experience. And in Bawa’s case, actually raising the status and value of the tradition.

iv) “Reinterpreting Tradition” – “the use of contemporary idioms” to transform traditional formal devices in “refreshing ways” as in “Frank Lloyd Wright’s transformation of Meso-American forms” into an invigorating modern idiom, “through an abstract and usually minimalist statement”.48

This paradigm is based on evoking tradition; we will therefore refer to it as the “Tradition-based” paradigm.

W. Lim applied the colonial bungalow formal concepts or types in the Reuters House, completed in 1990 as a way of evoking tradition (please see photograph in Appendix A, Figure A-12). The large pitch roof form with clay tiles, stilt-like wooden columns, and overall proportion evoke the colonial tropical architectural tradition, where the large overhanging roof in combination with stilt-like structures are set in lush green and wide open grounds, offering the character of shade and airiness. The structure is based on reinforced concrete constructional method and the programme is based on

48 Lim and Tan related this to ‘critical regionalism’ as described by Frampton (1983) in ‘Prospects for a critical regionalism’. Frampton borrowed the term ‘critical regionalism’ from Tzonis and Lefaivre, who started the term. Frampton, however, differed from the original meaning of the term. For more information, please refer to an updated version of the original writing, ‘Why critical regionalism today?’ Tzonis and Lefaivre (1990).
the owners’ modern lifestyle. This fits with the description of the fourth strategy of reinterpreting tradition with new technology and new programmes in an innovative way.

This paradigm can be encapsulated in a diagram as in Figure 1-2. The regional expression is based on the strategy of evoking tradition. There is an assumption that if traditional forms are faithfully followed, or lessons from traditional forms are followed, climatic comfort and convenience will be provided effectively. As for materials and means of building, it could be traditional, modern or mixed depending on which of the sub-strategies is employed in this paradigm.

Figure 1-2
A diagram for the “Tradition-based” paradigm

![Diagram](image)

Regional Expression (by evoking tradition)

Climatic comfort and convenience (assumed valid)

Materials and means of building (traditional craft or varying mix with the modern)

Most of the examples used to illustrate this “Tradition-based” paradigm are resort developments, small cultural and institutional buildings, and small-scale residential projects with ample land and budget for the use of traditional timber, roofing materials, stone walls, water bodies, and large open landscaped grounds. This approach is less likely to be suitable for solving the region’s high-density high-rise urban problem. Another problem
with the deliberate and continuous over-emphasis on traditional forms may over-shadow experiments and the emergence of new cultural forms.

The "New Screen and Louver Kitsch" paradigm

The third paradigm, the "New Screen and Louver Kitsch", is a new kind of kitsch. Similar to the usual historicist 'Neo-Greco-Kitsch' referred to earlier, they are bad copies of some forms in the past. The "New Screen and Louver Kitsch" is about bad copies of the modern tropical expressions without the appropriate application or performance. How did this type of kitsch develop?

First there is the stereotyping of the modern tropical image. The modern louver for instance has been used frequently as a sunshading device and therefore is visually associated with tropical architecture. The louvers on a facade that do not effectively shade a space may still be wrongly judged as effective with the genuine sunshading devices because they look similar or are 'representative of' (Kahneman and Tversky 1982b) those that worked, and give the illusion that they are tropical heat and rain control devices to the passing eye.

Second, with the mounting emphasis on the production of environmentally appropriate architecture, by prominent regional advocates like Tay (e.g. 1990, 1994) and Yeang (e.g. 1986, 1987, 1994) for instance, there is a motivation to join in this course, or be politically correct at least. A designer who is not truly serious about struggling with the climatic requirements because he is too busy or he thinks the climatic factor is not so crucial or not a priority for his design, but yet desire to have the tropical image because of the watching eye of the public, the client, or the architectural fraternity, can still have a way out. Because of the stereotyping, he can join in the charade by applying a gesture of the typical tropical heat shading or rain shielding devices, for instance, as part of the aesthetic
composition for his building. The viewers will judge the buildings to be climatically responsive (even if they are not), and this creates the possibility for a consumerist exploitation of the screen and louver images, and gives room for the “New Screen and Louver Kitsch”.

An example, the newly completed Tanjong Katong Secondary School, by the Public Works Department in 1999, displays louvers of different sizes on various facades with apparently little effectiveness in shielding sun and rain (please see photograph in Appendix A, Figure A-13). The huge louvers clearly shade blank walls and the small windows are not shaded. The small louvers at the corridors do not appear to offer much shade or rain protection. The staircase is fully glazed and exposed to the same external condition of solar radiation around the building, posing the problem of the greenhouse effect. All these points lead one to suspect all the attempts at ‘climatic modulation’. Such is an example of the “New Screen and Louver Kitsch”.

Another example, the competition winning design by Architect Vista for the Balestier Institute of Technical Education was completed in 1997 (please see photograph in Appendix A, Figure A-14). The building design looks elegant, full of screens and louvers that give the impression that it is a building that will perform well in protecting the occupants from solar radiation and rain in the tropical climate. But on closer examination, the corridors facing West and East are not adequately protected from the sun or the rain. Similar to the previous example, the main vertical circulation staircases are boxed up with glass, which will only create greenhouse effects. It was also interesting to note that it was simply described by a writer in an article for the *Singapore Architect* journal (SIA 1998) as an architectural design that has responded to the climate.

An example of a different category of building, House No.5, Lorong 105, Changi Road, designed by Look Architects, was completed in 1997 (please see photograph in Appendix A, Figure A-15). The ‘cubist’ composition is an interesting interpretation of a house, but there is something inconsistent about the provisions for climatic control. The provision of a set of four large
"sun-shading" fins seems to indicate that the designer had intention to protect the interior of the house from the Western sun, but the provision of large expense of glass on the same façade that will create greenhouse effect contradicts the designer's efforts in the provision of protection from solar radiation. These make the genuine interest in the consideration for effectiveness of climatic control suspect.

Figure 1-3
A diagram for the "New Screen and Louver Kitsch"

- Regional Expression (base on the stereotype of new tropical images)
- Climatic comfort and convenience (actual effectiveness of climatic modulation is suspect)
- Materials and means of building (modern or mixed with limited traditional)

The "New Screen and Louver Kitsch" paradigm is not a responsible paradigm to emulate. The diagram, in Figure 1-3, can serve to encapsulate the paradigm. The expressions, materials and means of construction are mainly modern, but there could also be a mix. The regional expression is based on exploiting the stereotypes of new tropical images that can play on judgement because of the biases resulting from representativeness. The effectiveness for climatic performance is suspect.

Apart from these three paradigms that typify the extreme positions, there are other variations with different emphasis in the goals and approaches to achieve their tropical architecture. Below are three examples.
Community development through tropical design

In the Bedok Court Condominium, completed in 1985, the architect, Cheng Jian Fenn (J. F. Cheng), created tropical urban streets and forecourts in the sky. These allow for maximising open court activities in front of each apartment unit in the sky with ample opportunities for growing familiarity and social contacts (please see photograph in Appendix A, Figure A-16). According to Cheng he wanted to bring back a similar social-physical experience he knew well that existed in traditional tropical kampungs (villages) in Singapore.\(^{49}\) Cheng referred to Jane Jacobs' argument (Jacobs 1962) for the importance of the street as 'vital organs of a city' or community and interaction nodes, and a need for 'certain loss of privacy' or sacrifice of privacy necessary for knowing and interacting with others in the modern society rather than having a maximum privacy. One may be suspicious of the success of such sky-court concepts, but a survey of the project and residents has shown a high 90% vote from residents that they are highly conscious of a strong sense of belonging, ownership and security. And that life will be very different without the tropical streets and forecourts in the sky (Bay 2000). The success is attributed to the fact that all kinds of activities ranging from gardening, dining, and children playing and studying can happen on these conducive airy and sheltered forecourts to each unit, with neighbours visible to each other, day in day out for familiarity and community structure to develop. The quality of tropical 'village' living was achieved, and recreated with innovatively modern building technology, materials and aesthetic language. Here the architect was more concerned with the social implication of the 'streets'. It is noted that the spaces are indeed adequately protected from the rain and shaded from the harsh sun, open and airy with lots of cross-ventilation, conducive for what he planned for not just the individual home user, but for the community.

\(^{49}\) Author’s discussion with J. F. Cheng, Singapore, 1999: Cheng was the design architect in Associates Group Architects for Bedok Court Condominium.
Symbolic emphasis in tropical design

In a recent work, The Market Place, completed in 1995, the architect Tang Guan Bee (G. B. Tang) elevated the status of the traditional market in the neighbourhood by introducing new tropical form reminiscence of the old market, but with totally new materials and technology (please see photograph in Appendix A, Figure A-17). Even though the roof of The Market Place is of metal cladding and a barrel shape instead of the corrugated asbestos pitched roofs of the past, it captures the ambience of the old markets, the sense of the large overhanging and airy canopy.\textsuperscript{50} This demonstrates an act of ‘moving forward and a little backward’ at the same time, and serves to galvanised the people to a place they knew, and lift up the spirit of the sleepy old suburban town.

Juxtaposing of two paradigms

In the newly completed Institute of Southeast Asian Studies in 1998, the PWD architect Cheah Kok Ming (K. M. Cheah) has created a dialogue between old and new tropical forms in an innovative whole (please see photograph in Appendix A, Figure A-18). The pitch roof, stone materials, and landscape are reminiscence of Southeast Asian traditional architecture and are relevant cultural subject to the centre. These are juxtaposed with the prominent modern glazed air-conditioned boxes, connected by airy covered walkways, and shaded with metal sun-screening devices. The result is a cohesive composition of old and new, of tradition-based paradigm and climatic-based similar to ‘line, edge and shade’ paradigm, where the

\textsuperscript{50} Author’s discussion with G. B. Tang, Singapore, 1999. Tang is the sole-proprietor of TANGUANBEE ARCHITECTS.
consciousness of the regional and modern are augmented simultaneously. Moving in and around the building, one is conscious and intrigued by the architectural dialog of the old and the new. Here the poetics of the tropical elements is the chief concern of the designer.

**Analysing some aspects of practice, overconfidence in thinking, and errors**

The case of tropical architecture as demonstrated through design examples described in this chapter can help us draw some general observations:

*The tropical design problems were difficult problems.*

There were multiple requirements varying from climatic comfort and convenience, symbolic, spiritual, cultural, social needs and considerations for appropriate building technology and materials, with conflicting demands for attention from the architects. Environmental control was not necessarily a priority concern. For example, in the People's Park Complex and Woh Hup Complex, the concept of city and urban live was more important, and in the tradition-based paradigm the continuum of traditional cultural and physical entities. The main concerns were symbolic, social, and poetics for example of The Market Place, Bedok Court Condominium, and Institute of Southeast Asian Studies respectively.

*Human judgement and intuitive thinking were used without the aid of quantitative calculations*
In the example of the design for the Singapore Conference Hall and Trade Union House, and the Malaysia Singapore Airway Building, even though the architects referred to Olgyay and Olgyay’s *bioclimatic* guidelines that could be used for quantitative calculation, they only used the guidelines for heuristic design thinking without making calculations. They use the guidelines in *pre-parametric* (Ulrich 1988) and *qualitative* (Kuipers 1994, 8) ways (this will be discussed in detail in the next chapter).

*The architects referred to various existing architectural examples, types, rules and principles as design precedents*

In the “Tradition-based” paradigms, the traditional forms were referred to as types for applications in new design problems. In the “Line, Edge and Shade” paradigm, traditional forms were also referred to but more for use as rules and principles51, and for examples52, as overlapping precedent knowledge.53 The traditional forms were referred to for the rules and principles such as, “if you need to shade a space effectively from the sun, use a large roof with great overhangs”, and for mapping the example of traditional form, operation, and performance over to the new design problems by analogy. The traditional roof form for instance has the property of working (operation) as a sun-shading device, and provides protection from the sun (performance) which could be analogically mapped over to new forms for similar operation and performance.

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51 Rules and principles are established knowledge. Rules here are used in the sense of ‘a usually valid generalisation’. Principles are ‘comprehensive and fundamental law, doctrine, or assumption’, and are stronger and more established and institutionalised then rules.

52 An ‘example’ or ‘case’ contains aspects of multi-faceted decision processes as a holistic solution. It allows one to focus in detail and depth on the domain problem without loosing applicability.

53 In this study, we refer to architectural precedent knowledge as knowledge embodied in rules and principles as well as cases (examples) of a pre-existing built environment or building, where the “area of overlap between reasoning with established knowledge and reasoning with cases is the use of precedents” (Tzonis and White 1994, 19).
Some problems of beliefs and assumptions, and errors in the practice of tropical design

From the three tropical design paradigms we discussed above, we can see the shift of the degree of emphasis on the importance of climatic comfort and convenience, and the variation of assumptions about climatic performance in relation to guidelines referred for designing.

For the “New Screen and Louver Kitsch” paradigm, climatic performance is not really important. Image is more important. The likelihood of errors in the design with regards to climatic performance is very high with the use this paradigm. Matching images of new screens and louvers to those on existing buildings that worked well do not guarantee similar performance in the new design. These kinds of errors are what Tversky and Kahneman (1982a) refers to as errors resulting from biases called illusions of validity.

For the ‘Tradition-based’ paradigm, the continuum of traditional formal elements and cultural memories are most important. Climatic performance is assumed to be effective as long as the design is faithful to the traditional form. This however can be in error. For instance, the way climatic modulations were provided and associated with the traditional forms in the past may not be applicable to the high-density urban context of today. The adaptation of the traditional forms may not necessarily produce similar effects. When traditional forms are made in new modern materials, there may also be errors.54 The assumption that faithful reliance on traditional forms will lead to effective climatic response may be in error.

The “Line, Edge and Shade” paradigm opens up possibilities for the high-rise and high-density urban designs, but the “Tradition-based” paradigm has not indicated this relationship and the possibilities. Instead, in

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54 Similarly, Fathy (1986) warned about changing the materials of traditional elements for environmental control to modern materials, where the resultant effectiveness of climatic modulation may be seriously lacking.
the foreword to ‘Contemporary Vernacular: Evoking traditions in Asian Architecture’ by Lim and Tan (1998), Charles Correa seems to suggest that this can be simply done, saying: “What we do not have to do is design mass housing for people. On the contrary, the wonderfully flexible and pluralistic language of vernacular habitat already exists. All we must do, as architects and planners, is adjust our cities so that this language becomes viable again. And once this is accomplished, then our remaining task will be to just get out of the way.” This looks like a strange assumption and belief, and more likely an illusion that the tradition-based paradigm itself will settle the problems of high-density and high-rise designs.

In the example of the completed building, Bishan Institute of Technical Education, the architect used the “Line, Edge and Shade” paradigm. The main precedent references were the climatic rules and principles derived from indigenous buildings he assumed to be effective in climatic performance. The overall climatic performance of the building was found to be generally adequate (we will this building in detail in Chapter 5). This means that the heuristic approach of design employed by the architect was reasonably effective. However, there were some errors in the design judgement and decision for the amphitheatre area that has a large roof over it. This could be due to overconfidence in judgement owing to cognitive biases associated with the heuristic means of thinking with the precedent of large roof.

In this chapter we discussed the case of architectural design in the tropics. Tropical architecture is about building design that is appropriate in expression, in response to the climatic condition of the tropical region to meet the social and cultural needs, and that is constructed with compatible materials and means of building. Tropical architectural design is a difficult problem with multiple requirements and often with conflicting priorities.
Time and mental resources are also limited in practice. It is not possible to consider all possible alternative solutions before the architect selects a solution. The architect employs heuristic judgements, without quantitative calculations or simulations, as an economical and efficient way of solving the difficult design problem, with reasonable effectiveness. He uses precedents embodied in examples and rules for his design thinking. But there are also errors in design that could be due to overconfidence in his judgement based on the precedents used. This could be due to illusions or biases that lead to errors.

Following the observations above, in the next chapter, we will discuss more in detail how and why precedents are used as heuristics in the design thinking process. We will discuss in general how and why designers overcome the difficulties in the design problem with the use of precedents. We will then use this understanding to examine a selected list of publications on design guidelines for environmental control to see their general characteristics and suitability for use in relation to architectural design thinking.
CHAPTER 2

DESIGN PRECEDENTS IN TROPICAL ARCHITECTURE

*Design thinking with the use of precedents as heuristics with analogical, pre-parametric and qualitative means, and problems of biases in tropical architecture*

In the last chapter, we noted various design difficulties in the case of tropical architecture; the conflicting requirement, time and mental constraints, the paradigms, beliefs, and assumptions. We briefly noted that architects in their practice of tropical design, generally used precedent examples¹, experience, rules and principles² for their design thinking heuristically, without the aid of analyses with calculations and simulations.

In this chapter, we will discuss in detail how and why precedents are used as heuristics in the design thinking process. We will first discuss in general why designers are often obliged to overcome the difficulties in the design

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¹ A ‘case’, or an ‘example’ contains aspects of multi-faceted decision processes as a holistic solution. It allows one to focus in detail and depth on the domain problem without losing applicability.

² Rules and principles are established knowledge. Rules here are used in the sense of ‘a usually valid generalisation’. Principles are ‘comprehensive and fundamental law, doctrine, or assumption’, and are stronger and more established and institutionalised then rules.
problem with the use of precedents with analogical, pre-parametric, and qualitative means of thinking, without mathematical calculation.

This understanding will be used to examine various available publications on design guidelines for environmental control to see their general characteristics and suitability for use in relation to architectural design thinking. We will examine how and why architects use precedents embodied in these guidelines as heuristics.

We will then discuss some aspects of the problems of using heuristics in the examples in Chapter 1. We will highlight several instances of overconfidence in assumptions and beliefs in the process of design by various architects. These over confidence could be associated with cognitive biases that lead to errors in judgement and decision-making.

The use of precedents to overcome difficulties in design

Design thinking, in general, is characterized by intentional actions and formulations of ways of changing the state of things towards desired end states (Simon 1969, 55). The design problem however is not a well-defined

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3 This is a theoretical concept that design thinking like problem solving is a search through a problem space where one state is transformed to another repeatedly till the goal state is achieved. Alan Newell and Herbert Simon (1972) demonstrated the theoretical concept of 'means-ends analysis' as one important limited human heuristic strategy for problem solving with a computer program, and the idea of the 'problem space' with initial state, sub-goal and goal state in the thinking process. In this approach the problem is solved by repeatedly determining the difference between the current state and the goal or sub-goal state, then finding and applying a permissible operator (step or move) to reduce or eliminate the difference, till the goal state is achieved. They started presenting their inquiries and the information-processing framework from 1956, influenced by gestalt psychologists such as Karl Duncker (Gardner 1985). Incidentally greater understanding of human thinking and confidence in employing computers for understanding problem solving grew with this influential project in 1972. Whilst the concept of 'problem space' helps in the discussion and understanding of design thinking and problem solving in general, the 'means-ends-analysis' as a means of solving problems is only one of many human heuristic means, and a limited one that can solve only well-defined problems (Newell and Simon 1972).
or comprehensively stated problem with a clearly defined goal (e.g. Lawson 1997; Runco 1994; Schon 1983). Design thinking is a creative process, and is a kind of problem solving and inquiry with vague and unknown goals, clearer only when something new is discovered or created towards the end of the process. The design problem in practice is difficult to be solved with incomplete information, limited time and human mental resources. It is not possible to analyse and search through all possible alternative solutions, multiple contingencies, and multiple conflicting demands, as doing so will lead to combinatorial explosion. Not many aspects of the problem can be easily quantified.\footnote{It is noted that for quantifiable problems, many assumptions are also made based on experience to reduce the variables needed for computation in order to avoid combinatorial explosions for practical reasons. In practice it is not practical or possible to consider all alternatives exhaustively.}

Donald Schon (1983, 49-50) referred to this condition as practice with ‘uncertainty, instability, uniqueness and value conflict’, where the architect managed his design work by using his experience, intuitive and human feel, rules-of-thumb and previous examples, developed through years of education and practice.\footnote{Please refer to Schon (1983) where he expounded on the epistemology of practice with ‘reflection-in-action’ based on human heuristics, and that ‘technical rationality’ is not compatible with professional practice.}

Numerous projects on artificial intelligence have been modelled with theories of human thought and some of these have shed light on the understanding of various aspects of human thinking and problem solving. With the assumption that we can observe the computers perform complex acts of information processing without any need to assume that they are conscious, the \textit{modern cognitive psychologist} can draw the analogy of information processing and therefore understand thinking through discovering the ‘software of the human brain’ (Evans 1995, 60).\footnote{Evans (1995, 59) commented: “From the view point of a modern cognitive psychologist both introspectionists and behaviorists might be seen as half right. The behaviorists were probably right in their contention that thought cannot be studied effectively via introspection. The mentalists, on the other hand, were correct in asserting that complex behavior could not be explained without reference to internal mental processes”. The mentalists’ and associationists’ conception of conscious thought was discredited by experiments where subjects showed no conscious experience at all in their judgement (Humphrey 1951), and Freudian theory that behavior could be determined by repressed emotions in the unconscious mind (Evans 1995). The behaviorists could not explain the\ldots”}

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therefore discuss what some of these findings are about human thinking and problem solving, and the use of precedents as heuristics.

**Design problems cannot be solved by analytical approach alone**

In an early example of devising a general-problem solver in the 1960’s for architectural design, Serge Chermayeff and Christopher Alexander, in their book *Community and Privacy* (Chermayeff and Alexander 1963, 115), advanced the following thesis that: “The most powerful heuristic the designer can find is to state the problem so clearly that the statement itself becomes his lever”. However, the design problem cannot be solved by mere analytical means without precedent knowledge.

Tzonis and White (1994, 4-5) criticized that Chermayeff’s and Alexander’s ‘design methodology’ depended chiefly on the belief that a solution would emerge by analysing the problem clearly and exhaustively with the computer, replacing tradition and the ancient human process of trial and error. Because the design problem was growing very complex, it was believed that the analytical power of the computer could analyse the relationship of multiple criteria better than the human mind and help man to produce solutions automatically.

flexibility and economy of thinking. The cognitive psychologist argued that man has the capacity to plan and there is the existence of internal representation and processing (Miller et al. 1960). See William James (1890/1983), and Howard Gardner (1985) for details and development on the science of the mind as a process, not an entity, with attention, consciousness, short-term and long-term memory, functionalism, artificial intelligence, etc, to the cognitive science of today. Also see Howard Rachlin (1989) for a discussion on the resolution of cognitive psychology and behavioral psychology, and functionalism. At the same time, the studies in cognitive neuroscience are also adding onto the project of understanding how the mind works, and models for the computer neural network: (e.g. Gardner et al. 1996; Kosslyn and Koenig’ 1992; Churchland and Churchland 1998).
That was shown to be greatly inadequate because this kind of analysis itself could not produce the solution, and there was also the limitation of the computing capacity to cope with combinatorial explosion for architectural design.

The paradigm began to be reversed in the second part of 1980’s for automation-based architectural design, following studies in machine learning and thinking by analogy with domain precedent knowledge, modelling after human thinking. If a human being begins to imagine all alternatives before he arrives at a solution for a complex problem, it will take too long or it will exhaust his mind capacity before he reaches a solution. This is the reason why human beings employ various heuristic means of generating solutions, to shorten the process and prevent combinatorial explosion.

**Experts use heuristics as shortcuts in practice**

Tversky and Kahneman (1982a) gave many examples of experts in real-life conditions of practice, who are obliged to use the necessary heuristics to solve various problems, in politics, business, and the clinical and legal professions. ‘Heuristics’ used here are in the sense referred to by Tversky and Kahneman (1982a) and Schon (1983) as thinking relying on the use of intuition, human feel, experience, rules-of-thumb, examples by analogy for judgement and decision making in real life conditions, without normative analysis based on mathematical representations.

7 Bazjanac (1974, 8) also noted in an older text that the design process is not strictly sequential, and design problems are ‘wicked’ where a linear step-by-step procedure cannot produce any solution.
8 There were other aspects to the Chernayeff and Alexander paradigm, and similar attempts with modifications by others that had problems, and that restricted developments in automated problem solvers. There have been many attempts to incorporate precedent domain knowledge, and other human heuristics into computer software for problem solving and design. More discussions in Automation Based Creative Design: Research and perspective, edited by Alexander Tzonis and Ian White, (1994).
9 Heuristics are necessary, very powerful and capable of solving problems of great uncertainty. George Polya (1973, 113) asserted that human beings are obliged to use ‘heuristic reasoning’ based on induction and analogy for solving mathematical problems when the actual complete proof is uncertain at first.
Payne (et al. 1997, 183) argued that heuristics simplifies the search for solution through a problem space of multiple alternatives efficiently, and that "the use of heuristics often represents intelligent, if not optimal, decision making." Fang (1993, 96) mentioned several examples of heuristics use to generate solutions for difficult problems, such as 'generate-and-test', 'means-ends analysis', 'hill climbing', and 'analogy"\textsuperscript{10}, and argued that most of these techniques in architectural problem solving are related to precedent knowledge in design.

We will next discuss various aspects of precedents and how they are useful and necessary for solving the difficult design problems.

**Precedents are necessary for solving design problems in practice**

Historically, most architectural design judgement and decisions were made with reference to precedents, and precedent knowledge is an important element in architectural design practice (e.g. Collin 1971; Clark and Pause 1985; Rapoport 1990; Tzonis 1992; Fang 1993).\textsuperscript{11} In this study, we refer to architectural precedent knowledge as knowledge embodied in rules and principles as well as cases (examples)\textsuperscript{12} of a pre-existing built environment or building, where the "area of overlap between reasoning with established knowledge and reasoning with cases is the use of precedents" (Tzonis and White 1994, 19).

Peter Collins (1971, 13) drew a parallel between the practice of the legal profession and architectural profession. For both the architect and the lawyer, past examples or cases are studied, and referred to for assisting their

\textsuperscript{10} These human heuristics are also employed in the development artificial intelligence for economy in problem solving. Please refer to P. H. Winston (1992) for more discussions.

\textsuperscript{11} It is noted that the use of precedents for design thinking is not the only way used by architects. In this study we focus on the use of precedents in design.

\textsuperscript{12} A case or an example contains aspects of multi-faceted decision processes as a holistic solution. It allows one to focus in detail and depth on the domain problem without losing applicability.
arguments and judgements in the new cases they handle.\textsuperscript{13} Tzonis and White (1994, 18) observed that formal order in architecture, like in law, is important, and that “architectural reasoning is more akin to legal reasoning than it is to many parts of engineering, in that it is much less reducible to mathematical and computational formalisation: its problems are ‘ill-structured’, and related, like those of law, to a wide range of human modes of thought and objects of interest”.

A case can be referred to in its entirety, ‘capturing its holistic properties’ or can be referred to for ‘parts of precedents’\textsuperscript{14}. Schmitt (1994, 41) demonstrated, with a computer program using Case-Based Design method, that new design problems with incomplete information could be solved by adapting, modifying or combining existing cases of buildings. In a new problem of incomplete information, it is difficult to see or state all the multiple criteria, specific design elements required, and state the final goal yet to be created. However, if a precedent example is used, then the structure and relationship of most of the various aspects of design considerations can be traced and be considered with much ease.

In many instances, there is no point ‘reinventing the wheel’ for every architectural solution. Solutions in architectural precedents can be quickly ‘borrowed’, modified, and applied for various portions that match or are similar in the requirements of the new design problem, and re-adapted for new creations.\textsuperscript{15} This will overcome the tremendous difficulty in the design problem, avoids combinational explosion in thinking, and saves time and mental resources, to cope with the problem in practice, including more attention for innovation and creativity.

\textsuperscript{13} Please refer to Ashley (1990) for discussions on the process of arguments and judgement in the legal practice, and to Collins (1971) for more discussions on the relationship of legal arguments and architecture.

\textsuperscript{14} As referred by Tzonis and White (1994) to the use of entire cases for Case-Based Reasoning discussed by Schmitts (1994) and ‘part of precedents’ discussed by Kuhn (et al. 1994).

\textsuperscript{15} Clark (1985) shows a whole array of architectural precedent examples from history, analysed for their characteristic attributes in design to serve as guidelines for architects’ new design.
Precedent knowledge can also be embodied in rules and principles. Byran Lawson (1997) referred to Ken Yeang’s approach to design as one where practical, symbolic, and radical constraints are absorbed into an overarching set of ‘guiding principles’ informing his design process for a climate that remains essentially unchanged. The term ‘guiding principles’ is used more in the sense of ‘rules-of-thumb’ for design, observed from many incidences in the past, which the architect has eventually regarded as ‘principles’ through his general use. The use of such precedent knowledge also avoids computational explosion, and saves time and mental resources.

**Precedents as analogical means of thinking**

Precedent knowledge, embodied in buildings and non-buildings, can be applied by analogy, to the design of a new building. Generally, if you are faced with a difficult problem, a useful heuristic is to find a similar or related incident and map by analogy to the solution to the current problem (e.g. Polya 1973; Ashcraft 1998; Holyoak et al. 1997).  

Precedent knowledge discussed above can be used by analogy to help one understand problems in many other situations with similar structure, and generate solutions.

One good example in architectural design was the use of the precedents of ‘huts, ships, and bottle-racks’ by analogy by Le Corbusier as heuristics for his creative design of Unite d’Habitation, a high-rise modern housing project (Tzonis 1991, 153). The ‘pilotis’ were inspired by analogy to huts on poles, the roof deck was a re-interpretation or transfer of ideas of decks of ships for sun and recreation, and the modular structure of the apartment units was fashioned after the similarity of the properties of bottle-racks. The

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16 Ken Yeang was cited by Bryan Lawson (1994, 1997) as an example of the architect that develops ‘guiding principles’ for practice.

17 See e.g. Gick and Holyoak 1980; Holyoak and Thagard 1997; Kolodner 1997 for social and educational examples of the application precedents by analogy as heuristics for thinking.
morbidity, operation, and performance of each element were mapped across contexts for new possibilities.

Analogy, in a sense, can be called a 'happy (mis)conceptualisation'. Things are not seen in their usual frameworks or categories or context, even though there are similarities in their structure. It is 'happy' because it is potentially useful to see A as B or C. It must be noted that while the use of a precedent by analogy opens up new possibilities through change in conceptual filters, it does not guarantee creativity, but acts as a rich catalyst for creativity. The use of precedents by analogy helps to generate new solutions quickly and efficiently for the difficult design problems.

**Precedents as pre-parametric and qualitative means of thinking**

Precedents, as discussed above, can be used by analogy of previous cases and by applying rules to similar new context. These heuristic means are also used with pre-parametric and qualitative means of thinking, without the aid of quantitative formulae for mathematical calculations, for design thinking and problem solving.

Herbert Simon (1969) claims that animals including people do not always solve problems in the best possible way by optimising because it is too difficult. Instead man have developed convenient methods of problem solving, based on limited information and limited cognitive apparatus to arrive at the best solution possible under the circumstances. Simon termed this process *satisficing*, based on his argument of *bounded rationality*, where

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\[^{18}\text{It is like a ‘mistake’, departing from normal or usual conceptualisation (in the sense of categorisation) for the object considered. See Quine (1981) for more on conceptual filter, schemata, conceptual apparatus, and representation. Hilary Putnam (1987, 1988) argued that we could not say that facts are independent of conceptual choices, implying seeing A as B, and at a more fundamental level Kant explained how we see an object in the world through a phenomenal experience constrained or facilitated by innate categories.}^\]
it is rational\textsuperscript{19} if one solve his problems, not to the extent of a complete maximisation, but sufficient to get by and achieve the goals in life.\textsuperscript{20}

As mentioned above, human beings employ many and different heuristics as shortcuts, without quantitative calculation. These heuristics are pre-parametric and qualitative in nature.

\textit{Pre-parametric means of thinking}

In the example of the use of precedent by analogy above by Tzonis (1992), the various entities and properties of the examples of ‘huts’, ‘ships’, ‘bottle-racks’, are mapped over mentally by \textit{pre-parametric} (Ulrich 1988) means of thinking without reference to quantitative details. Another example of pre-parametric thinking with the use of precedent knowledge can be seen in this statement, “If you want to protect a space from rain, then use a roof with that particular shape”, where the quantitative aspect is not directly referred to in the thinking. Precedent knowledge can be used with just pre-parametric means of thinking, but it can also be used with qualitative means of thinking.

\textsuperscript{19} Simon’s (1969, 1986) sense of ‘bounded rationality’ in a similar sense as ‘minimal rationality’ discussed by Christopher Cherniak (1986).

\textsuperscript{20} In a similar sense, Donald Schon (1983) argues that the practice of the professional does not fit the model of ‘Technical Rationality’; where in ‘Technical Rationality’ everything must be based on positivistic scientific methods of maximisation. Schon refers to ‘Technical Rationality’ as the positivist epistemology of practice, where professional practice is a process of problem solving with choice or decision through selection, from available means based on scientific mathematical theories, of the one normative best suited to established ends. He also criticized that scientific methods tend to oversimplify many things for normative analysis, and do not represent the actual problem adequately. He argues for an alternative epistemology of practice of the professionals, where psychiatrist, architects, lawyers, scientists and engineers alike rely heavily on reflective methods of thinking (he calls it reflection-in-action) for their practice. Please refer to Schon’s (1983) \textit{The reflective practitioner: How professionals think in action}, for detailed argument on the ‘non-Positivistic’ epistemology of professional practice.
Qualitative means of thinking

In the everyday practice, the designer for example may not always know or work with the exact numeric quantitative magnitude of physical elements when he is making judgements and decisions accordingly. He works with estimates and qualitative descriptions of mechanisms in the physical world with qualitative reasoning (Kuipers 1994, 8). For instance, he can describe, compare, and rank the order (ordinal) of different window sizes visually, stating whether they are larger or smaller, or large, medium or small, and estimate and describe the size of a roof as too large or too small for a particular purpose by comparison to a precedent example.

An example of the use of precedents with both pre-parametric and qualitative thinking will be in this statement, “If you want to protect this space from rain, then use a roof of this shape and size larger than the example”. So the designer is usually able to solve the problem of design without the need to refer to the exact quantitative magnitude of design elements, by using precedents with pre-parametric and qualitative means of thinking. These are powerful means for satisficing in design problem solving.

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21 Benjamin Kuipers (1994, 1) described the expert in specialized domains, for instance in chemistry, mechanical engineering, and medicine as, “The expert is characterized as much by his or her “trained intuition,” “educated guesses”, and “expert common sense” as by the ability to use specialized instruments or advanced computational methods.”

22 Qualitative reasoning is based primarily on ordinal or ‘landmark’ values compared for order as well as equality, and the difference can be used to process even complicated decisions and operations. See Kuipers 1994, for more details.
Precedents and design guidelines for environmental control

We will now examine several available publications on design guidelines for environmental control to see their general characteristics and suitability for use in relation to architectural design thinking. We will discuss how and why architects use precedents embodied in these guidelines by analogical, pre-parametric and qualitative means for design thinking.

Many environmentalists like Donald Watson (1991, 1995) deliberated on the education of morality and the need to incorporate environmental ‘principles’ in architectural design, in the age of ecological crisis. For Watson, the scarcity of environmentally sound design stems from a lack of integration between ecological and architectural principles. He suggested five metaphors where an environmental architecture can be conceived as ideas formed in their making, similar to Le Corbusier’s metaphor of his architecture as “machine for living” (Watson 1991). These five metaphors, the building as a “natural heat exchanger”, “natural light diffuser”, “micro-climate”, “biological system”, and “ecological niche”, emphasize the need to treat design as technology, integrating them with other human, structural, or cultural concerns in the making of architecture. These metaphors are precedent knowledge that can be use with analogical and pre-parametric thinking processes for environmental design.

One of the basic question a designer asks is how he can go about designing for environmental comfort and convenience, knowing the factors discussed earlier in the last chapter, including solar radiation and sun path, glare and lighting, temperature and temperature change, precipitation (rain), humidity, air movement, and noise and air pollution that have impacts on the level of human comfort and convenience. One of the ways is to refer to his personal experiences of various environments he has been in the past including those he has designed. The other is to refer to various publications on environmental design for guidelines that varies from metaphors
mentioned above, to rules and principles, typologies, examples, and quantitative analyses with calculations and simulations.

As discussed in Chapter 1, we will limit our discussions about environmental design to an architectural design that provides for comfort and convenience for the occupant of the building, and minimize energy consumption, mainly with passive systems. The passive system includes design that is responsive to the climate with appropriate building orientation, building configuration and building fabric design.

Limitations of typologies for environmental control

A traditional 'type' or 'typology' embodies concepts of design, 'ready-made' for application with the assumption that it is suitable for the new context\(^2\). The traditional form has proven to be effective for environmental control for comfort, and the concept can be used for a new design to produce a similar result of human comfort if the conditions are similar.

In the modern context there are also modern building typologies that serve as guidelines for new designs. Hawkes (1996, 46-55) identified the problems of various modern typologies such as the 'deep plan' that conserves heat, and various developments of types for design in the temperate climatic environment. Hawkes (op. cit., 51) criticized that quantitative typological models have become stereotypes that were uncritically adopted for new projects repeatedly, and that they are "founded upon a 'scientific' basis which is largely inaccessible to the majority of designers". He commented that each stereotype ought to be examined very closely to "reveal its validity as a general solution".

\(^2\) It is noted that traditional type is seldom copied strictly in the modern context, and there are overlaps of rules, types and examples used as guidelines.
Hawke suggested building up a collection of precedent cases of actual buildings in operation as 'complete environmental systems', with both the quantitative and pre-parametric descriptions, for guiding future design thinking, and avoiding the stereotype effects of highly deterministic typologies. The result "would be a richness of solutions inspired by the particular nature of each problem and the achievement of building science would find its true place within a proper understanding of the nature of design" (op. cit., 55).

Typologies provide concepts that are suitable for use with pre-parametric and qualitative design thinking, but are not as rich as actual examples for use as precedents.

Limitations of quantitative analyses for environmental control

Quantitative analyses with mathematical formulae for calculation, require a lot of time and mental resources, and are not suitable for used by architects in practice who has limited time and mental capacity, and multiple conflicting demands. We will discuss just one example to illustrate the difficulty involved in using quantitative analysis to guide design.

Let us take a case of a designer who wants to design for thermal comfort for the interior of a new building on a particular location in the hot and humid climatic zone with passive means of environmental control using, for illustration sake, the quantitative guidelines by Olgyay and Olgyay (1963).

What he has to do is first to make evaluation of the extent he has to reduce heat through sun shading, and increasing ventilation.\(^{24}\) He has to plot temperature and relative humidity data on the bioclimatic chart (assuming an existing chart is available for that region where his building site is) at regular

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\(^{24}\) Assuming he is not using mechanical means to reduce humidity, and also assuming that the appropriate building material is used for maximum heat insulation, using a different set of calculations.
intervals throughout a year to show the extent of overheat condition to establish the amount of sun shading and air-movement to design to. He then needs to use a set of geometric considerations and radiation intensity calculations to determine the effectiveness of shading devices and orientation of the building in his design, and a set of calculations based on the rate of air-flow through the building in combination with the inside flow patterns. He then keeps adjusting his design of the building and checking the rate of air-flow and effectiveness of shading and intensity of radiation with the same procedures till he achieves an intersection of the variables of temperature, radiation, humidity and air-movement that rest within the comfort zone in the bioclimatic chart.

Now this is just for the design of a simple building. Imagine he has to design a more complicated building with different types of windows and sun shading devices, different sizes and configurations of rooms, etc. As discussed in the previous section, these tend to lead to computational explosion if the designer needs to consider all the parameters, and procedures for computation, including the repeats of procedures he has to go through as he adjusts his design.

This design analysis is just for the predictions of thermal comfort offered by the design, not including the control of noise, lighting, etc, and other architectural matters to consider, including architectural expressions, cultural/social needs, appropriate building technology, etc, discussed in Chapter 1.

Olgay who had been involved in architectural practice himself, admitted, “In practice we can not expect an architect or builder to go through all those elaborate calculations” (1952, 23).

To reduce calculations for the architect, Olgay and Olgay (1963) created various graphical charts, and geometric ways of calculations so that the architect may work on them graphically to assess the effectiveness of orientation, sun shading, pattern and rate of air-flow and achieve the thermal comfort level. These charts and guidelines (please see Appendix B, Figures B-3 and B-4 as two examples of these guidelines) are limited as it is not
possible to represent all possible scenarios of design, and therefore the designer has to make many assumptions, and human estimations and interpolations between the limited types and numbers of charts when he uses them.\textsuperscript{25}

Olgay (1952, 23) also proposed and developed categories of buildings, types with distinct characteristics that he called ""vocabulary""s of architectural elements" that can be used to guide new designs\textsuperscript{26} (please see Appendix B, Figure B-5 for an example of graphical guidelines for building form designs).

These show that it is impractical for the architect, without other expert helps, to employ quantitative calculation methods during the design process, and that the human pre-parametric and qualitative means of judgement are essential to the architect to cope in practice.

There are other literatures dealing with similar mix of quantitative, pre-parametric, and qualitative guidelines with more comprehensive aspects of environmental controls, including daylight considerations for lighting and glare, protection from rainstorm, building materials and constructional considerations, etc. These include Tropical architecture in the dry and humid zones (Fry and Drew 1982), Tropenbau: Building in the tropics (George Lippsmeier 1980), and Manual of tropical housing and building (O. H. Koenigsberger et al. 1974).

Some of the current publications are also similar in nature (e.g. Brown 1985; Lam 1986; Zeiher 1996; Givoni 1998; Gallo et al 1988; Yeang 1999; Edwards 1999; Thomas 1999; Mendler 2000). Similar to the case of Olgay and Olgay above, these publications generally show a few calculation methods limited to very simplified and specific environmental concerns. They essentially provide many examples, types, rules, and principles as suitable for analogical, pre-parametric, and qualitative design thinking by the architect.

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{25} There are many sets of charts and simplified geometric means of calculating and estimating sun shading, air-movement, etc in Olgay and Olgay (1963) and Olgay and Olgay (1957).
\item \textsuperscript{26} Please refer to Olgay and Olgay (1963) for more information.
\end{itemize}
\end{footnotesize}
With the development of more and more computer simulation programmes for the assessment and prediction of design for environmental control, the tedious and complicated calculations can be automated and the task made easier. Let us examine the use of such approaches by the architects.

**Limitations of computer simulation with expert advice**

A. Mahdavi and K. P. Lam (1993, 10) observed a general attitude of scepticism among architectural students toward the use of ‘rational decision-making tools’ (‘rational’ in the sense of decision-making using mathematical quantitative approaches with calculations and computer simulations), and suggested that this was owing partly to the lack of communication and integration, where the design exercise in the design studio and the transfer of scientific and technological knowledge were viewed as separate courses and entities.

Mahdavi and Lam (op. cit.) had integrated the use of computer simulation in an experimental design studio project with students, for a limited set of environmental (climatic) assessment, and found that the simulations have helped the students positively in their early stage of design. (However, it is not sure if students will respond favourably if a full set of complicated environmental factors using computer simulations is introduced in the early stage of design, where the expert advice may be needed in the design process.)

It is certainly important to develop multi-disciplinary systems of computer simulation that can be used in the onset of the design process to assist design decision at each stage, with the advantage of savings in lifecycle energy cost (Mahdavi and Lam 1993, 9).\(^\text{27}\) Wong, Lam, and Feriadi

\[^{27}\text{Please refer to Lam (1994) for similar arguments for an integrative design process, and the use of computer simulations in the early stage of the design process.}\]
Cognitive Biases in Design

(2000) made a thorough study of various computer simulation programmes available commercially and from research institutions internationally\textsuperscript{26}, and surveyed the architectural and engineering design practices in Singapore on the use of simulation tools for building design works. Their survey results "confirmed the general feeling that the usage of performance-based simulation tools for building design and evaluation in Singapore was very limited" (op. cit. 729), and listed several reasons for the limited usage:

1. "Inherent system limitations of current simulation tools",
2. "Structure of existing building delivery process", and
3. "Prescriptive nature of the building legislation".

They proposed a 'co-evolution' of the design process, the development of the simulation tools, and the building regulations (op. cit., 734). This is certainly a good direction to approach the problem to ensure that the simulation tools are 'user-friendly' to the way architects think and work during their multi-criteria design process.

At the moment computer programmes for environmental design are not simple enough for the architects to use in practice without the help of experts to operate the programmes and interpret the results.\textsuperscript{29} In a sense, this is not sympathetic to the nature of creative design thinking of the architect, and adds demands on his limited time and mental capacity. In the light of this, when designing, the architect may necessarily delay the involvement and interruptions of engineering experts\textsuperscript{28}, at least not in his initial design stage, because architectural design as described in the earlier section, is difficult and uncertain.

Wong, Lam, and Feraidi (2000) also noted that many developer clients who are not using the buildings themselves are not willing to pay the time

\textsuperscript{26} For more information on the state-of-the-art available simulation tools, please refer to Wong, Lam, and Feriadi (2000).
\textsuperscript{27} The expert's intuitive and heuristic guesses, assumptions, interpolations, interpretations, and advices are still required to assist the architect in the evaluative processes.
\textsuperscript{28} At least till improved simulation tools are available. Things will improve with better understanding of how the artistic and creative mind works so that simulation tools are sympathetic to the nature of the architect's design process.
and cost to engage simulation tool experts in the design team. Does this mean that the architect will not be able to design a building that has reasonably adequate environmental control considerations? On the contrary, designers will still be able to use his expert heuristic judgement and decision-making process with reasonable success, but may not be accurate all the time. In a sense, it will benefit the architect if both heuristic processes and simulation tools could be improved for his better use.

Hyde (2000, 59-61) who shared similar concerns about life-cycle cost argued that calculations and computer simulations are not suitable (at least for the moment) for the architect’s initial design process. He argued that calculations and computer simulations with expert help are suitable for diagnosis of design effectiveness after the architect’s initial design stage, so as to demonstrate to the client the effectiveness of environmental design and to make minor detailed adjustments are needed in the detail design stage for working drawings before the construction.

Hyde proposed design ‘strategies’ to ensure a tropical climatic responsive initial design (so that only minor adjustments at the more detailed design stage). These ‘strategies’ (to be discussed below) embody precedent knowledge suitable for pre-parametric and qualitative design thinking.

Design guidelines that are generally suitable for analogical, pre-parametric, and qualitative design thinking

A survey of current publications on environment design guidelines for climatic design and sustainability showed that they embody precedents that are generally suitable for use in analogical, pre-parametric and qualitative design thinking processes (e.g. Jones 1998; Slessor 1997; Vale 1991; Barnett 1995; Marras 1999; Cottom-Winslow 1990 and 1995; Crowther 1992; Farmer 1999; Collier 1995; Briffett 1994; Ong 1996; Flanagan 1996; Stitt
1999; Hawkes 1996; Harrison 1998; Yeang 1999; Hyde 2000; Edwards 2000). Like the case of Olgyay and Olgyay above, they mainly give general design guidelines showing many case examples, typological concepts, and rules and principles. In some examples, diagnostic quantitative data of specific buildings are provided as demonstration of the extent of success of such examples, and can usually be used as guidelines for heuristic judgement in new design work, as they do not provide any information on the methods of diagnosis or calculations that may inform the user for future use. Some of these books discuss the need for quantitative means of assessment, but do not directly provide the know-how, but refer to third party experts and environmental engineers for computer simulation tools (e.g. Edwards 2000; Hyde 2000).\footnote{For a list and descriptions on the state-of-the-art available simulation tools, please refer to Wong, Lam, and Feriadi (2000).}

Few recent publications are specifically written for the tropical climatic context, and those that are written for the tropical climatic context are generally suitable for pre-parametric and qualitative thinking. The tropical city: Towards an ecological basis for urbanisation in Southeast Asia (Powell 1993), Tropical architecture and interiors (H. B. Tan 1994), and ‘Towards an ecologically-responsible urban architecture’ (K. S. Tay 1994) for example, gave essentially design arguments and precedent cases and rules suitable for pre-parametric and qualitative design thinking.

One of the latest publications, specifically applicable to tropical architectural design, is by Hyde (2000). As mentioned above, Hyde proposed design ‘strategies’ for a tropical climatic responsive design for the architect’s initial design process. In fact, to demonstrate his proposal of climatic responsive design approach, he used the example of a house he designed. In this example, he diagnosed the effectiveness of the design with simulation tools and calculations only after the initial design was completed. For the refinement of the design, minor adjustments to the choice of materials for instance, are made at the detail drawing stage (op. cit., 50).
Figure 2-1
Climatic types, climate modification strategies and building tactics for hot humid climates, (after Hyde 2000, 57)

<table>
<thead>
<tr>
<th>Climate type</th>
<th>Adverse climatic elements</th>
<th>Climate method</th>
<th>Response strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot humid</td>
<td>Rain, heat, high humidity, insolation, small diurnal variation</td>
<td>Minimize heat gain, maximize ventilation, maximize shading</td>
<td>Thin plan with axis east-west, cross-ventilation, high ceilings, ventilated roof, window shading all year, shaded veranda</td>
</tr>
</tbody>
</table>

Figure 2-1 shows what Hyde called strategies for design in the hot and humid climate. These are precedent rules and concepts for design suited for the architect’s pre-parametric and qualitative design thinking process.

In this section we discussed that the designer has the option of using his personal limited experience, or of using typologies, examples, rules and principles offered in many publications for the design for environmental control. He uses them with pre-parametric and qualitative ways of thinking, without mathematical calculation and simulation. We have shown the difficulty of the use of quantitative in environmental design, and that it is necessary and practical to use precedents as heuristics to solve design problems. There are however problems with the use of heuristics which we will discuss below.
Precedents and heuristic biases in design thinking

Heuristics are used to reach quick, reasonably effective, and creative solutions, but they may also lead to errors and fail because of cognitive biases (e.g. Tversky and Kahneman 1982a; Baron 1994; Evans 1995; Osherson 1995), which are unwarranted confidence in believing the likelihood of an outcome. From the case of tropical architecture we observe various beliefs and assumptions that architects made in their applications of the precedents to their new designs, and that there were some errors and possible areas of errors. These are:

1. The universal-applicability myth
   When referencing precedents, the designer may assume a universal-applicability of the case to all new design problems. There may be overconfidence in this assumption because it may not be true all the time. For instance, the assumption that precedents of traditional forms may be used in thinking about the design in high-rise high-density context because of the similarity of climatic conditions and requirements for environmental protection may not hold true all the time because the may be differences in the context where environmental factors operate differently. For instance, the air-movement characteristics around and through traditional buildings in open space are unlike those around and through the high-rise high-density housing units, because several parts of the buildings may be congested, while other parts may be exposed to strong winds.

2. Ill-structured information
   Information of precedents may be ambiguous or vague, for instance the description of porous buildings. What is the extent of porosity for a traditional house example? This is more difficult to gauge than the

70
extent of overhang of a roof. If a vague notion of the property of a precedent exists, then the use of such a precedent knowledge for thinking in a new design may lead to errors.

3. Result oriented process – optimistic mindset
The mindset of the creative designer is optimistic in the midst of complexity and ill-defined problem space. The positive result oriented process is a habit and a pattern for the creative designer. Architectural publications generally discuss innovations and successes, and few discuss the failures (opposite of successes). This positive mindset may have implication on the way the designer map the precedent onto the new design problem, overlooking exceptions of inconsistencies or incompatibilities. In the example of Bishan ITE for the “Line, Edge and Shade” paradigm, the architect is very optimistic about using large overhangs in the manner of the examples of traditional houses for the new design, and has confidence that it will work. But how accurate is he in his judgement in this different context? Is he over-confident? In fact one of the major space in the building complex with a large roof and extended overhang has shown to fail in the protection of the space below from rain and heat. We will look into detail about this particular building project as a more detailed case study to see the extent of the problem, in Chapter 5.

These errors or potential errors discussed above could be related to the overconfidence in the beliefs in the precedents that the designers were not sensitive to because of biases. This could be because biases gave them the unwarranted confidence that the design would work, leading to errors.
In this chapter, we discussed in detail how and why precedents are used as heuristics in the design thinking process, and the related errors. We discussed in general how and why architects are obliged to use precedents as heuristics with analogical, pre-parametric, and qualitative means of reasoning. We then used this understanding to examine various available publications on design guidelines for environmental control to see their general characteristics and suitability for use in relation to architectural design thinking. The architect use precedents embodied in these guidelines heuristically. We noted some possible problems in the beliefs and assumptions in the precedents used and the errors and potential errors that may arise. These instances of overconfidence can be related to cognitive biases. We will discuss an interdisciplinary methodology of investigation to examine this problem in the next chapter.
CHAPTER 3

THE PROBLEM OF COGNITIVE BIASES

Methodology to study the problem of heuristics and biases in design thinking: With the case of tropical architecture

In the last two chapters, we discussed how and why architects use precedents as heuristics with analogical, pre-parametric and qualitative means for solving difficult design problems in tropical architecture. We noted possible problems in the beliefs and assumptions in the precedents used and the errors and potential errors that may arise. We also noted that heuristics thinking could have associated cognitive biases that lead to overconfidence in beliefs of the likelihood of various environmental outcomes. This could lead to errors in design judgement and decision-making. We proposed that cognitive biases associated with heuristics are linked to the problem of inaccuracy of design judgement and decision-making in tropical architecture. In this chapter, we will state the problematic and propose an interdisciplinary method of investigation to understand the problem of cognitive biases. We will discuss the cognitive theoretical framework, and the case study method for the case of tropical architecture and a specific building design. We will discuss the framework for developing a cognitive model for improvement, and the testing of this tool.
An interdisciplinary method of investigation

Precedents are used with analogical, pre-parametric and qualitative means for their solving difficult design problems. Daniel Osherson (1995, 74) refers to this type of 'reasoning mechanism' that is non-Bayesian or non-normative as representing imperfect but convenient heuristic for reducing the mental cost of reaching a judgement and decision. Osherson (1995, 63) noted that the human eye is capable of very accurate comparison of lengths for instance, but at times the use of heuristic methods are affected by cognitive biases or illusions that result in error in judgement and decision-making. For example, in the case of assessment of soil quality by soil experts with the eye and feel of the hand, which has to be done very regularly without the help of measuring instruments and normative analysis (Gaeth and Shanteau 1986, 450). Laboratory tests and procedures take too long, and are expensive. So human judgement and intuition, unaided by measuring instruments and normative analyses, are depended upon to judge the soil quality and make decision to plant large areas of crops with success. But there are also errors due to illusions in thinking, and Gaeth and Shanteau developed a training programme to reduce the biases due to attention on irrelevant information (op. cit).

In the case of tropical architecture, as discussed in the previous chapters, architects tend to work with precedents that are similar to their new design problem, and precedents that they believed to be successful, for their design thinking. They tend to be optimistic in their result-orientated design approach, and may be overconfident in their judgement of various outcomes of design performance. Tversky and Kahneman (1982a, 1-11) had identified several types of heuristics, and two of these are particularly relevant for our

1 Please refer to Gaeth and Shanteau (1986, 450) for more information.
discussion. We will discuss representativeness, which relies on similarity, and availability, which is based on the ease of recall and imaginability (as in the sense as something that is famous and successful is easier to recall and imagine) (detail in Chapter 4). These are related to the ways architects use their precedents. Both these heuristics have their associated cognitive biases, which are illusions that lead to errors in judgement and decision-making. We propose that this is linked to the errors in the design judgements and decisions for design in environmental control. We will now state the problematic and propose the interdisciplinary method of investigation that will be used to examine in detail the problem cognitive biases and the way for debiasing with the case of tropical architecture.

**Basic assumptions and problem statement**

We assume that the professional architect is honest, responsible and rational, neither insane nor a deliberate deceiver, nor ignorant of the advantages of appropriate architectural design. ‘Rational’ here is used in the sense as Simon’s (1969, 1986) definition of ‘bounded rationality’, where it is ‘rational’ if one solves his problems, not to the extent of a complete maximisation, but sufficient to get by and achieve the goals in life. In the case of tropical architecture, responding to the climate will contribute towards the physical comfort and convenience of the user, and fits into the larger important picture of contemporary eco-sustainability drives, wherever it can reduce energy consumption. It can also yield correspondingly unique architectural expressions of the tropical region, which offers a much-desired local character to combat the globalising effects of architecture around the world. Despite the knowledge of all these advantages, there are many buildings that are inadequate in their performance in climatic modulation, and yet appeared to be adequate even to the rational architect. We propose that this can be due to biases affecting the well-motivated and honest
architect who uses precedents as heuristics in his design judgement and decision-making.

_Problem statement_

The problems of inaccuracy in judgements and decisions in architectural design for the tropical climatic environment, even though the architect is most of the time rational in his daily activities, are linked with heuristic _biases_. Appropriate refocusing of the mind on opposite outcomes in judgement with a _rebuttal_ mechanism can _debias_ these _biases_, and thus improve design thinking.

_Biases_ constrain judgements of adequacy of design for environmental control, and in turn constrain design decisions, resulting in designs that perform less than judged adequacy (Figure 3-1).

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2 ‘Architect’ here means a designer or a team of designers who designs a building project in the architectural domain.

3 ‘Rational’ here, as mentioned earlier is used in the sense as Simon’s (1969, 1986) definition of ‘bounded rationality’, where it is rational if one solves his problems, not to the extent of a complete maximisation, but sufficient to get by and achieve the goals in life. This is in a similar sense to Cherniak’s (1986) ‘minimal rationality’.
Cognitive theoretical framework

An interdisciplinary research method is used. Method draws on knowledge from cognitive science, environmental engineering, and architectural theory. The method is aimed at constructing a model to represent and account for how the concerns of externality (architectural environment) are mapped or inadequately handled in the mind, resulting in seemingly irrational decisions and external pragmatic errors. The bottom-up understanding of the case of tropical architecture, will be interpreted top-down with the theory of action, decision theory, and design methods to understand the problem of heuristics and *biases* in design thinking (Figure 3-2).

**Figure 3-2**
Errors in design judgements and decisions is linked to heuristic biases

<table>
<thead>
<tr>
<th>Design thinking</th>
<th>Interpreting design thinking in terms of cognitive psychology</th>
<th>Cognitive science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural design</td>
<td>To understand the problem of judgement and decision making in the case of tropical design</td>
<td>Theory of heuristics and <em>biases</em></td>
</tr>
<tr>
<td>Tropical design</td>
<td></td>
<td>Theory of action</td>
</tr>
<tr>
<td>Environmental control</td>
<td></td>
<td>Decision theory</td>
</tr>
<tr>
<td>Problem of errors</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The cognitive theories of Tversky and Kahneman (1982a) about heuristics and *biases*, judgement and decision-making by *representativeness*
and availability will be central in the cognitive framework of discussion in this study. Their relationships with conceptual categories, attention, and memory will be discussed in detail (in Chapter 4). These will be used together with the theories on conceptual frame-system and architectural knowledge representation, and the framework for debiasing below, to understand the how and why of the problem, and to develop a tool for improvement.

**Cognitive framework**

Different designers have different rules to design thinking and acting, implicit or explicit, based on their beliefs. However, basically the making of decisions is based on certain universal structure of thinking. According to Tzonis, Berwick and Freeman (1978) a minimal structure of thinking can be represented with the universal concepts of Norm, Fact, and Directive, in the Kernel of Conceptual System, which is a particular scheme of interlocking relationship of norm, fact, and directive that constrains design thinking. Design thinking consists of two processes (Tzonis and Oorschot 1987):

1. The process of generating a plan (proposal for a course of actions) from a programme, and
2. The process of justifying a plan in relation to a programme.

In this conceptual system (Tzonis et al. 1978, 5), certain fact (belief that ‘IF large overhang, THEN protection from rain and sun along corridors’) corresponds with a norm (the deontic or normative, say ‘it is desirable to provide adequate climatic protection’), and generates a directive (a plan or justification, ‘provide large overhangs’). The directive in turn becomes a norm corresponding to further facts or form justification for further plans. The fact judgement and belief in the fact is supported by a backing and reinforced in turn by a base for its trustworthiness. This is based on several
theories of action and decision-making. A distinction between the descriptive and prescriptive mode of thinking, and the relation between one concept permitting another are based on Rescher, Logic of command (1966), and Von Wright, Norm and action (1963). The descriptive thinking, argument, justification and claim of a fact are similar to a model of argument by Toulmin et al. (1984).

The Kernel of Conceptual System will be used alongside with, a framework for the representation of architectural knowledge, which consists of interlocking relationships of performance, operation, and morphology in a certain context (Tzonis 1992, 147). (We will refer to this framework as the Performance-Operation-Morphology Framework in this study). These theories of action, decision-making, and architectural knowledge will be interpreted in the case of tropical design with detailed discussions later in Chapter 6.

Framework for debiasing

Preceding the therapeutic proposal will be a short discussion of various strategies suggested in various studies in judgement and decision theories and behaviours. Hal Arkes (1986, 587) noted that awareness of the presence of a bias is not enough to eliminate that bias substantially. According to him the awareness helps a little. There is a need to consider alternatives for sharpening the judgement and decision-making process. In one example, Hoch (1985, 719) has shown with experiment that subjects improved in their prediction of their personal future chance of getting certain jobs more realistically if they were asked to think of the opposite outcome or negative possibilities. We will consider the use of appropriate rebuttals (based on Toulmin et al. 1978, 98) as a strategy for debiasing, and discuss an extension to the theoretical model developed in Chapter 6 towards a therapeutic model for improvement. The therapeutic strategy and model will be discussed in detail, in Chapter 7.
Descriptive case study approach

Architectural design is diverse in nature and application-oriented, and it is difficult just to discuss it abstractly. The case study allows us to specify the decision processes, multi-faceted and holistic problem, and focus in detail and depth on the domain problem without loosing applicability (Yin 1993, 1994; Hamel et al. 1993). The case study method to be used here is a descriptive (Yin 1993, 21) bottom-up way of understanding the problem through tracing various architects’ design processes in tropical architecture. The descriptive case study looks at the structure and relationships of factors leading to decisions. Based on the extensive arguments put forth by Yin (1993, 1994) and Hamel et al. (1993) for the strength of the single case study, we assume that we can learn and make generalisation from the understanding of design judgements and decisions from the single case.4

The case of tropical architecture, in general and specifically in Singapore, is used to understand how and why architectural design is done and the characteristics of the problems. The case of tropical architecture in Singapore is chosen because it is an example of design practice rich with information about the context, design work, thinking processes, successes and errors in designs suitable for the research discussion. Also the understanding derived is applicable to the practice of design in many rapidly developing countries in the region that share similar concerns and conditions of practice.

The case is studied in two parts. The first part of the case study is a preliminary case study to review the various paradigms of practices in Singapore to understand the general practice, the architect’s dependency on

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4 Please refer to Yin (1993, 1994) and Hamel et al. (1993) for more details about the single case study, and the power of generalisation from the study of the elements and structure of the decision process in the single case, as opposed to making statistical survey of multiple cases.
pre-parametric and qualitative design thinking, and the problems (as discussed in Chapters 1 and 2).

The second part is the case study of a specific building project, which was designed and completed by an architectural practice that is committed to producing responsive tropical design. The findings about the precedent entities and properties, and the analysis of the problems of design errors in relation to possible biases will be discussed in detail in Chapter 5.

Cognitive experiment

The extent of suspected biases at work and strategies for debiasing are to be examined with a series of limited test cases based on established methods in the cognitive sciences, to test the judgements of designer-subjects on the adequacy of various pre-selected climatic designs. This experiment will be set up based on the understanding from the descriptive case studies, the theoretical and therapeutic model for improvements.

The test cases will be setup to ascertain the efficiencies of two debiasing strategies on both the biases due to representativeness and availability. The first debiasing strategy to be tested will be ‘the warning of the possible biases at work’; to see if judges in the experiment improve in their accuracy of judgements. The second debiasing strategy to be tested will be ‘the introduction of rebuttal mechanism’; to see if a change in the mental framework improves judgements. The certainty of test results and indications of improvements will be checked with normative method of assessment of climatic adequacy and statistical analysis for true positive results (based on ‘Drawing conclusions from data: Statistical methods for coping with uncertainty’, Wickens 1998, 585-634). The details of the test set-ups, results, and analysis will be discussed in Chapter 8.

The findings of this study will be evaluated for its reliability, implications to practice and education of architectural design. It will also be evaluated across other design discipline if the theoretical interpretation holds and
where the limits are. Suggestions will also be made for further investigations into the various aspects of the domain of cognitive psychology and architecture. The details of these will be discussed in the final chapter (Chapter 9). (The step-by-step procedure of the entire study can be referred to in the Introduction.)

The problem of cognitive biases in design thinking is defined and situated. Precedent knowledge is used as heuristics to solve complex architectural problems with limitation of time and human mental resources. Heuristics are efficient and can be reasonably effective, but can also be associated with biases that lead to errors in design.

The method of investigation has been discussed. The problem is to be investigated and understood by interpreting the theories of action, decision, design method, and in particular judgement under uncertainty with the case of tropical architecture.

To form a top-down view of the problem, we will discuss various related theories of illusions in thinking in the next chapter, Chapter 4, so that we can use them for discussion in the case study of a specific building project in Chapter 5.
CHAPTER 4

ILLUSIONS

Illusions related to human judgement and decision-making

In this chapter we discuss various theories on the problems of illusions related to general human perception, misjudgement and misconception, and pertaining to heuristics and biases associated with judgement and decision-making under uncertainty, in order to form a top-down framework for discussion and analysing the case study of a specific building design for environmental control in the next chapter, Chapter 5. We will first discuss some general aspects of illusions to have an idea of what illusions are, and then discuss in detail two heuristics that will be used to examine the way precedents are used in the design process in tropical architecture.
Some aspects of illusions in thinking

General illusions in human perception and conception

Illusions leading to misjudgement with human perception

There are many examples of illusions leading to misjudgements with human perceptions, where what are seen and judged are inconsistent with what is really there, or with what is really logically implied. Considering the observed competence of human beings, judgement must ordinarily be reasonable, as perception must usually be sensible. However, when these conditions obviously fail, we have the opportunity to explore how judgement must operate better. The followings are examples of misjudgement with human perception due to certain illusions.¹

Figure 4-1.
Muller-Lyer. A well-known visual illusion

A familiar illustration is provided by the way we see the upper line, in the famous example by Muller-Lyer (Figure 4-1), to be longer than the lower line, even though the actual physical lengths are the same. This kind of

¹ Finding that illusions occur does not necessarily imply that they are empirically important either as a direct effect on lives, or as a diagnostic tool for probing cognition. But the first step in making the case that they can be important in both ways is to show that they actually exist.
illusion is rather persistent in that even after knowing the fact that the two lines are of the same length, the diagram still exerts on the perceiver such that the upper line tends to look longer. This type of illusion cannot exactly be corrected, but the belief can be changed after knowing the fact. This is somewhat like a second intuition having experienced the illusion and the fact. Osherson (1995) asked if this illusion imply that the human visual system lacks a mechanism for comparing length of lines. He noted that the answer is no, “because in the absence of arrowheads we judge the comparative length of parallel lines with great precision” (op. cit.). This means that there could be factors that could interfere with our naturally able intuitive, pre-parametric and qualitative judgements with the eye and mind. In this case it is the interference of the arrowheads that caused the illusions.

Figure 4-2.
Another example from Frisby's *Seeing* (1979) will give a more complex case where what is seen and read in the mind is in error. This poster was an actual announcement that had been purposely designed with the mistake that may 'escape detection' until it was printed (Figure 4-2). In this example, the word 'SRING' looks complete and is illusorily mistaken as complete. The misspelled word 'SRING' matches or fits the description of 'SPRING' in the context of 'SPRING SEASON' and the programme of the announcement. When the mistake is once noticed, the illusion completely disappears, and is corrected. However, this does not mean that it will not happen again in another similar context, if the perceiver forgets or is too busy to pay enough attention to a similar poster. If he or she remembers or pays attention then he or she may avoid the illusion and notice the mistake.

**Misconceptions - naïve physics**

People usually have difficulties in thinking because of incorrect or incomplete domain knowledge. McClosky (e.g. 1983) has provided interesting examples of misconceptions or faulty mental models that people often have, in the understanding of motion in the physical world known as naïve physics.

McClosky (1983, 300-305) experimented with students who had and had not completed at least one college physics course. In these examples (Figure 4-3), 51% of participants tested indicated that the marble would continue in a curve motion when it emerged from a curve tube, when the correct motion is straight (model A). For the example of the airplane dropping a bomb while travelling at a constant speed, only 40% of the participants could imagine the correct trajectory (model A). The rest of them figured it to be straight at an angle downwards, curved backwards and straight down. For the case of the ball rolling over the cliff, 26% could not get the correct trajectory of fall (model A).
Figure 4-3
Naïve science, faulty mental model (after McClosky 1983)

Conceptions of the path of a ball emerging from a spiral tube

Conceptions of the trajectory of a bomb dropped from an airplane

Conceptions of the trajectory of a ball rolling over a cliff
Cognitive Biases in Design

Everyday examples would include turning up the heater thermostat thinking that it will heat up the room faster, and pushing the elevator button several times the way one rings a door bell, believing that the elevator car will respond faster (Ashcraft 1998). The human minds are consistently susceptible to certain kinds of illusions associated with various common mechanisms used in human thinking. McClosky (1983, 307) found out that in the naïve physics examples above, people developed remarkably articulate naïve theories of motion based on their everyday experience, where the assumptions of these theories are quite consistent across individuals. And the various forms expressed used the same basic theory, which are not compatible with the principles of physics and are in error.

Some faulty mental models persist even when the individual is aware of the inconsistencies. In the case of ‘pushing the elevator again’, or ‘knocking on wood’, these are ‘quasi-magical’ thinking that lingers on paradoxically (Shafir and Tversky 1992). However, with relevant instruction and training some thinking misconceptions can be corrected, in physics (e.g. Donley and Ashcraft 1992), and in probability (e.g. Fong and Nisbett 1991; more discussions on debiasing in Chapter 7).

What are some of these common thinking mechanisms that humans use that are susceptible to illusions? We will discuss some of the common heuristics used in human thinking under uncertainty and the associated biases in the following sections.

Illusions affecting judgement and decision-making under uncertainty

Many instances of the judgement of magnitude or sizes of objects in life, as in the case of pre-parametric and qualitative thinking in tropical architecture discussed in Chapters 1 and 2, are assessed without the help of measuring instruments and analysis with normative theories to achieve certain standards
of accuracy, where such calculations are based on mathematical models of physical principles and prediction of values based on statistical theories of prediction. Judgement of the height of a building, for instance, is estimated with the eye instead of measuring it. Decisions are made based on judgements of the likelihood of uncertain events, for instance whether rain is going to wet the people in a corridor with certain dimensions, which is being designed. Judgements, in this example, can be made with the comparison of the corridor being designed to past examples of corridors (which have proven to work where people were protected or failed to work where people got wet). The complete information of the quantity of rain and the full mechanics of how the rain falls and is affected by wind speed and directions are not readily accessible to the architect in practice, and therefore there is a lot of uncertainty. As discussed in Chapter 2, many judgements of likelihood of outcomes are made under uncertainty, whether it is about the outcome of an election, the future value of a currency, the guilt of a defendant, the success of an operation, the adequacy of the metal projections shading a building with many varying window shapes from solar radiation, and so on. We have discussed that architects use pre-parametric and qualitative aspects of precedent design solutions as heuristics in the practice of tropical architecture.

Tversky and Kahneman (1982a, 1) have shown how “people rely on a limited number of heuristic principles, which reduce the complex tasks of assessing probabilities and predicting values to simpler judgemental operations” in situations of uncertainty discussed above. A parallel is drawn between the assessment of likelihood of outcomes and the assessment of physical quantities such as distance or size. These judgements use heuristic principles to assess information with limited validity, like the apparent distance of an object determined in part by its clarity. The heuristic rule that ‘the sharper it appears, the closer it will seem to be’ is used to judge the distance.

Tversky and Kahneman (op. cit., 3-16) have studied and listed heuristics of representativeness (dependence on degree of similarity or match or fit),
availability (dependence on ease of recall or reconstruction), and ‘anchoring and adjustment’ (dependence on adjustment from an initial value) as the common heuristics human used in coping with judgement and decision-making under uncertainty. In the following section we will elaborate on the representativeness and availability that are more related to the case of design thinking in tropical architecture, and discuss their theoretical implications to understanding design judgement and decision-making.

Tversky and Kahneman have shown that the use of these heuristics can result in various biases\(^2\) or illusions that lead to errors (op. cit. 3-16). The example above on the assessment of physical quantities such as distance or size is used again, to illustrate the relationship of heuristic and bias leading to error. In the example, there is some validity in the rule that distant objects are usually seen less clearly than nearer objects. However, if visibility is poor, it may lead to an overestimation of the distance. If visibility is good it may lead to underestimation. An error in the estimation of distance may arise because of the dependency on this heuristic rule. An illusion or bias may develop due to the reliance on the heuristic rule that distance varies according to the degree of clarity of the object, leading to error.

*Biases* are found in human judgement of probability or likelihood of outcomes employing heuristics. We will discuss the biases associated with the common heuristics used for judgement and decision-making under uncertainty in the following section. These discussions on the heuristics and biases will also be used in the subsequent chapters for discussions with the case study of a specific building project in Chapter 5, the theoretical model in Chapters 6 and 7, and the cognitive experiment in Chapter 8.

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\(^2\) Tversky and Kahneman (1982a) have referred to biases as illusions leading to errors in relation to the particular heuristics, leading to overestimation or underestimation of probability values and predictions of likelihood of outcomes. This may not be confused with ‘bias’ in the sense that ‘he has a bias for red’, meaning he prefers, emotionally or ideologically, red as a colour or style. This does not mean that his ‘preference’ cannot cause a heuristic bias to develop, if the preference is related to the heuristic used.
Heuristics and biases

Kahneman and Tversky (1986) explained that the study of everyday judgement could be done with the study of judgement of probability of risk in the following statements: “Risky choices, such as whether or not to take an umbrella and whether or not to go to war, are made without advance knowledge of their consequences. Because the consequences of such actions depend on uncertain events such as the weather or the opponent’s resolve, the choice of an act may be construed as the acceptance of a gamble that can yield various outcomes with different probabilities”. In the same sense, risky choices such as humanly judging whether to choose a particular roof of certain form are made without complete information or advance knowledge of the possible outcomes or the aid of instruments, calculations or other normative prediction apparatus. The choice may be construed as a ‘gamble’, a ‘risk belief’ of the probability or likelihood of the roof performing. In this sense then all literature and studies on probability related to risk, overconfidence in the judgement of outcomes of instances, and biases are applicable for our discussion in the context of design judgement and choice or decision-making.

Representativeness and the illusion of validity

Representativeness – ‘A’ similar to ‘B’ therefore

Kahneman and Tversky (1982c) define the representativeness as: “A person who follows this heuristic evaluates the probability of an uncertain event, or a sample, by the degree to which it is: (i) similar in essential properties to its parent population; and (ii) reflects the salient features of the process by which it is generated.” The probability of A belonging to B, of event A originating from process B, of process B generating event A is evaluated by
the degree to which A is representative of (resemble or similar to) B. Osherson (1995) referred to this thinking mechanism as judgement by similarity.

For example, Tversky and Kahneman (1982a) tested subjects' judgement on the likelihood of the occupation Steve as a farmer, salesman, airline pilot, librarian, or physician. Steve was describe as:

Steve is very shy and withdrawn, invariably helpful, but with little interest in people, or in the world of reality. A meek and tidy soul, he has a need for order and structure, and a passion for detail.

The likelihood that Steve was a librarian was ordered as the highest, because the description of Steve was the most representative of the stereotype of a librarian. The way subjects ordered probability was exactly the way they ordered similarity. The unwarranted confidence, which was produced by a good fit (quality of match) between the predicted outcome and the input information, is called the bias or illusion of validity that can lead to serious errors in judgement and decision-making (op. cit.).

In the case of tropical design, a hypothetical case scenario could be like this. A modern building looks like the traditional 'tropical house' (a house that is typically believed to be cool, naturally ventilated and protected from rain). Because the image of the modern building fits or matches the features of the tradition 'tropical house' well, there could be a bias or an unwarranted confidence in believing that the modern building is a 'tropical house', merely basing on this representativeness.

Another bias is insensitivity to predictability, contrary to the practice of sound prediction, which should be based on relevant facts in the normative statistical method. In the example of Steve above, the relevant information to be used for prediction would be the base rate, for instance of how many in his town were farmers, salesmen, airline pilots, librarians, or physicians. In the case of the house example above, analogically there may also be a bias of
insensitivity to predictability, in this case insensitivity to the principles of normative theory of predicting adequacy of climatic environmental control.

Availability and biases due to imaginability

Availability – ‘A’ is easier to recall and imagine therefore

The frequency of a class or plausibility (likelihood) of particular instance is judged by the ease with which instances or occurrences can be brought to mind, recalled, retrieved in mind or by the extent of availability.\(^3\) Availability is convenient for assessing frequency and probability, because instances of large classes are usually recalled from memory better and faster than instances of less frequent classes (Tversky and Kahneman, 1982a, 11). For example, a doctor may assess the success of heart operation among old people by retrieving instances among past clinical examples from memory.

Tversky and Kahneman (op. cit.) gave a simple example of judgement involving availability:

Suppose one samples a word (three letters or more) at random from an English text. Is it more likely that the word starts with the letter r or that r is the third letter?

An algorithmic method to know the answer is to count from the dictionary. But since the subjects were asked to estimate, a heuristic was used. The result of the test showed that since it was easier to recall words that begin with r, subjects judged that there was relatively more frequency of words beginning with r. The fact is that there are more words with r as the third letter. The way we read and learn English words is in the left-to-right manner and we are used to remembering words according to word initials

\(^3\) The description ‘ease of retrieval in the mind’ matches the description of ‘accessibility’ in memory (Ashenft 1998).
and sound. It is therefore easier to retrieve this information from memory this way. This is a top-down bias where the way information is stored in memory has misleading effect on the way we access it (Ashcraft 1998). The availability is a way of thinking dependent on the ease we go about recalling information, and this leads to biases in judgement.

A class whose instances are easier to retrieve owing to familiarity, salience (or vividness) or recentness in occurrence will appear more than a class of equal frequency whose instances are less available. Tversky and Kahneman (op. cit.) showed that since famous or dramatic instances are more retrievable, they mislead judgement of their plausibility, and term these as biases due to retrievability of instances. Hearing about just one vivid story of an air crash can affect the estimate of frequency of accidents and therefore of airline safety far more than boring and dry statistical evidence can. News media dramatised air accidents more and give the impression that air travel is more risky compared to other modes of travel. Actually statistics show that travelling on the road is riskier because there are more instances of road accidents.

The more salient examples are also easier to imagine or reconstruct. The ease of reconstruction or imaginability causes biases of imaginability (Tversky and Kahneman, op. cit.)\(^4\) The availability increases with familiarity, fame, and salience, where each affects the ease of registering something in memory, the retrieval, and the reconstruction of such instance. Hypothetically and analogically, when judging the level of success in the performance of a design by a famous architect, it is easier to retrieve instances of him succeeding, and therefore judgement of success will tend to be overconfident on the high side. \(^5\)

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\(^4\) The availability of reconstruction is also called simulation heuristic, where Kahneman and Tversky differentiated this heuristic with that of availability in the sense that the latter is based on the case of recall and the former is based on the ease of construction, imagination or simulation (Kahneman and Tversky, The simulation heuristic, 1982).

\(^5\) Tversky and Kahneman (Judgement under uncertainty, 1982) also discussed another bias related to availability with an example by Chapman and Chapman, termed the bias illusory correlation. This could be understood as availability at work, where the strength of the associative bond, makes it easier to recall or imagine as instances, and therefore affects the judgement of the frequency of their co-occurrence. See also Chapman and Chapman (1969) for more details on this variation of availability heuristic bias due to imaginability.
Interest, preference, prejudices can also affect judgement of frequency (Ashcraft 1998). These increases salience and can lead to \textit{selective perception} (Hogarth 1987). Take for example a person who has a preference for Honda. He will tend to remember more of the instances of good Honda car performances than another brand and remember a lower frequency of Honda cars malfunctioning. The overall effect is a stronger belief and further association of Honda and better performance. Conversely, take a negative case where a boss is prejudice against a particular worker, that he is not so dedicated. The boss will remember more of instances of the mistakes the worker made, and believe and register in memory fewer instances, where he is trying to contribute positively. The worker and bad things are strongly associated, making it easier to imagine bad things happening with him. So when he is asked to judge the worker's performance, he will judge that the worker has not done many instances of contribution, or has made many mistakes, and therefore performs badly.

And if we correlate strongly fame to success, then the likelihood or plausibility of instances of success will also be judged higher, because it is easier to recall instances of fame and success, or imagine success. Analogically, a highly regarded or preferred architect will trigger \textit{biases of imaginability} of success, and be judged better for the performance of his designs. Similarly, a famous project by a famous architect will also trigger the same type of \textit{biases} and be judged with unwarranted levels of performance.
Other heuristics and biases

"In many situations, people make estimates by starting from an initial value that is adjusted to yield the final answer" (Tversky and Kahneman 1982a, 14). Tversky and Kahneman gave an example of where subjects were asked to estimate the percentage of African countries in the United Nation based on adjusting upwards or downwards from a random number between 0 and 100 given. Estimates were made anchoring on the starting points say 10 or 65, and adjusted if thought higher or lower to give the answer. Tversky and Kahneman entitled this heuristic as *adjustment and anchoring*.

They observed that different starting points yielded different estimates for judging the same value of an instance. They noticed that each estimate anchored on an initial value, resulting in the error of *insufficient adjustment*\(^6\), adjusted too close or conservative to the starting value (op. cit.). The estimates were 25 with starting point 10 and 45 with starting point 65. Meaning that they were closer towards each starting point where the upward or downward adjustments were insufficient.

Analogical to anchoring and adjustment that applies to numbers and statistical figures, E. C. Poulton (1989) has observed similar *biases* in the judgement of physical quantity of light and sound stimuli by the human judge without the aid of instruments. He termed them *contraction biases* in *Bias in quantity judgements* (Poulton 1989). In his experiments, the judgements of varying light and sound levels were adjusted too close to the given starting reference values in the experiments.

Analogically, in the case of designing a roof projection to shelter a corridor, the designer can start by recalling an example of roof of certain size from a famous building by a successful architect that he believed worked well, and make adjustment to it upward or downward accordingly to the dimension of the corridor. According to Tversky’s and Kahneman’s *bias* in

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\(^6\) Tversky and Kahneman (1982) found also other biases owing to anchoring, which are related to gamblers, and statisticians dealing with statistical distribution data. They are biases in the evaluation of conjunctive and disjunctive events, and anchoring in the assessment of subjective probability distributions. These biases are also studied by: Bar-Hillel (1973), Cohen, Chesnick and Haran (1972), and Alpert and Raiffa, for instance.
anchoring and adjustment or Poulton’s contraction bias, then there will be an insufficient adjustment, too close to the starting dimension of projection.

Cognitive biases lead to errors

From the above discussion of various heuristics and biases, one would observe similarities. Heuristics of representativeness, availability, and anchoring and adjustment, all lead to biases that affect judgement of frequency, plausibility, and propensity or the likelihood of outcomes of instances. These are related to the thinking mechanism of ‘match’, ‘ease of recall’ and ‘imaginability’, or primacy of ‘initial values’, while thinking about the instances. Biases are illusions that lead to errors in judgement and decision-making.

There are other aspects of heuristics and biases. In cases where one anticipates both positive and negative outcomes of some future event, Hoch (1984) found that generating favourable outcomes first tends to blind one to possible negative or opposite outcomes, and also makes one over-confident that a favourable outcomes will actually happen. One can be overconfident in the success of a design if the design or designer is given favourable description. Or that the creative designer’s mind is optimistic because he is in the habit of being hopeful to succeed, and he tends to see mainly the success of design elements he is designing as long as they are representative of something in the past that works. If one starts with a positive mindset, he tends to be overconfident, and to be blinded to the possible opposite outcomes.

Conversely if one starts with generating reasons why some outcomes may not happen, the confidence level will be more realistic or conservative in their prediction (Hoch 1985). Now, in the case of the design works of the famous designer, the judge will have to ‘wilfully’ start thinking of possible

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7 There are also biases related to past events, called the hindsight bias and bias in undoing in imagining ‘if only...’ (e.g. Aschraft 1998, Kahaneman, Slovic and Tversky 1982) that are not applicable to this study.
ways how the design may not work in order to be more realistic or conservative in his judgement. He has to imagine the negative despite the positive tendency due to the effect of availability biases owing to the fame of the design and success of the architect. This is interesting in the sense that one can employ this heuristic rule of ‘thinking about what can go wrong or the opposite outcome, as a guard against overconfidence’ in cases where things appear favourable.

In this chapter we have discussed illusions leading to misjudgements with human perception, misconceptions, and errors in judgement and decision-making under uncertainty. Judgements are made without complete information, and under time and resource pressures. Many decisions are based on pre-parametric and qualitative thinking, rather than normative quantitative calculations. Heuristics are economical thinking mechanisms to efficiently estimate various values and outcomes, allowing human beings to make quick decisions in life. Heuristics however have their attendant problems of biases that lead to errors. To what extent does the use of heuristics, especially representativeness or availability with the associated biases affect the quality of judgement and decision-making in the case of tropical architecture?

In the next chapter, Chapter 5, we will look closer at the precedent entities and properties used in design judgement and decision-making for environmental control, and the errors of inadequacy of design made, through a detailed case study of a specific building project. We will analyse these with the theories of heuristics and biases discussed in this chapter.
CHAPTER 5

A CASE STUDY OF A SPECIFIC BUILDING PROJECT

Understanding heuristics and biases in design thinking with a case study of a specific building project

In this chapter we will study in detail the precedent entities and properties used for heuristic judgement and decision-making in design for environmental control, and the errors in design, with a case study of a specific building project. We will analyse the errors made in this building design with the theories on heuristics and biases discussed in the last chapter.

First we will discuss the objectives and method of the case study, the selection criteria of the specific building project, and the multiple sources of data collection for the case study. Then we will look at how the building design, the design approach and design performances in environmental control are described by the architect and by the observer-writer. We will then analyse the characteristics of the design process and errors, in relation to the theories of heuristics and biases discussed in the previous chapter.
Objectives and method of the case study

Objectives of the case study

The objectives of carrying out a case study of a specific building project are to:

1. Understand the heuristic design process, how precedents are used by the designer in the design for environmental control, among all the other design considerations such as aesthetic, cultural meanings, usage, cost, constructional means and materials. To see how precedents are used as heuristics, where the biases and errors are, and what entities and properties of the precedents are involved.

2. Ascertain the success or failure of the design in environmental control from the users’ experiences through usage, in particular the aspects of solar heat, rain and ventilation. The adequacy of the design by normative computations and checks, including measurements and calculations done in other available studies of the same project.

3. Find out the match and discrepancy of the architect’s and observer’s confidence of design adequacy of the design, compared to the users feedback and normative checks.

4. Analyse the areas of errors, with the theories of heuristics and biases, in particular the illusion of validity, and biases due to imaginability, to see if these errors could be understood with these theories.
Selection criteria of a specific building project for the case study

The Bishan Institute of Technical Education (Bishan ITE) by Akitek Tenggara, completed in 1994, was selected for this case study because it has the following elements pertaining to design with precedents as heuristics with pre-parametric and qualitative means:

1. *The use of heuristic design thinking* - The building project is a design example executed with experienced-expert design thinking, with no normative quantitative calculations and simulations employed in the design process. It has shown overall success as well as some errors of design for environmental control, in the protection from solar radiation and rain (details to be discussed in the following pages).

2. *Knowledge and commitment to environmental design* - Akitek Tenggara and in particular its key leader and architect, Tay Kheng Soon (K. S. Tay) is committed to design for the tropical environment. Throughout K. S. Tay's career since 1963, he has not only implemented many designs with sensitivity to the tropical climate, but has also written and spoken as an advocate towards an environmently responsible urban architecture relevant to the modern urban tropical cities in the region. He, his partners and design teams at Akitek Tenggara are committed to the paradigmatic idea of 'Line, edge and shade', which has been discussed in detail in the previous chapter.

3. *Well-known architectural firm and building project* - Akitek Tenggara under the leadership of K. S. Tay has won many design awards (Bay at el. 1998) and is well known in Singapore and the region. K. S. Tay

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is also a prominent figure in the profession and was formally the president of the Singapore Institute of Architects. Tay Kheng Soon was invited in 1993 to be a judge along with Sir Norman Foster, Sir Richard Rogers and Philip Cox of the prestigious Quaternario Awards (Powell 1997), bringing Akitek Tenggara to higher international recognition. Bishan ITE is also a competition winning scheme and is a well-published work locally and internationally as a technologically poetic and a climatically sensitive design, including Line, edge and shade: Tay Kheng Soon and Akitek Tenggara (Powell 1997), Planning and designing developments naturally (Briffett 1994), and World Architecture (Steele 1995). This is particularly important as it is related to the theory of availability discussed in the last chapter, where fame increases the ease of imaginability of success to the observer who does a post-design evaluation of the design performance noted in the introduction.

4. Similarities of building features to various examples of tropical architecture - The building features of Bishan ITE share a kinship or semblance of many modern works in publications on tropical architecture including Tropical architecture in the dry and humid zone (Fry and Drew 1982) and Solar control and shading devices (Olgyay and Olgyay 1957), in the employment of various considerations and devices for climatic modulation and as architectural expressions. This is important in relation to the concept of similarity, representativeness, or match in characteristics or descriptions of instances relating to representativeness discussed in the last chapter.

5. Presence of passive means of environmental control - The activities require a mixed of non-air-conditioned space and air-conditioned spaces. A large part of the building such as several teaching spaces, assembly areas, canteen and circulation areas are non-air-conditioned,
requiring more stringent provision of design for passive environmental control. It is also an objective of the architectural firm to maximise the passive means of environmental control for lower energy consumption in the building operation.

6. Existing studies on the building performances in environmental control - There are existing measurements of climatic data and calculations done on this project by studies of the building that can be used for this case project study and analysis.

Descriptive case study with multiple sources of data collection

The case study is a descriptive study (Yin 1983, 21) with multiple sources of data collection (Yin 1994, 90). Data regarding the design and building performance were gathered with the following sources:

1. Interview with the architect\(^2\) with a set of general and specific questions on intention, precedence, and considerations besides climatic requirements (please refer to Appendix C for discussion questions and answers).

2. Collation of visual data; including photographs and drawings (please refer to Appendix C, Figures C-1 to C-9, for illustrations).

3. Collation of relevant information from publications and studies on the architect and especially on this building project. On-site assessment of adequacy of the building in climatic performance by researcher while

\(^2\) The design team for this project consists of Tay Kheng Soon (K. S. Tay), Patrick Chia and Henk Hermans. In this study, the design team will be referred to as the 'architect' as one unit sharing the common ideas and mode of working in Akitek Tenggara.
collecting data. One is the study of ‘Ventilation in buildings’ by Loo Chee Choon (C. C. Loo 1996) where measurements of solar radiation, temperature, and air-movement have been carried out at various parts of Bishan ITE. The other is ‘Computational design support tools’ by Loke Puay Yin (P. Y. Loke 2000) where the effective shading of the roof and large external louvers have been calculated with an expert computer programme for solar radiation studies.

4. Interview with users with questions of problems of climatic control around the building, which have not been identified in previous studies, in this case the problem of rain control or provision for protection from rain (please refer to Appendix C for survey questions and report on findings on the problem of rain).

Descriptions of the building, design approach, and performances

Descriptions of the building project

The Bishan Institute of Technical Education (Bishan ITE) is an educational complex with two 250-metre-long parallel blocks of accommodation separated by an 18-metre wide strip of landscaped open-street. The 3-storey block faces essentially the West and the 4-storey block faces the East. Various accommodations ranges from large non-air-conditioned areas, including assembly halls and canteens, to air-conditioned support facilities,

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3 The computer programme for computation of direct and diffuse solar radiation on facades based on empirical climatic data measured in Singapore is called SOL—ARIS, developed by Lam and Mahdavi, 1999.
including staff rooms, language laboratory, and library. The numerous non-air-conditioned small classrooms and study corner form the bulk of the spaces for learning (please refer to Appendix C, Figures C-6 to C-9, for illustrations).

**Design intention, precedents and process**

Bishan ITE was intended as an expression of the ideas of ‘line, edge, and shade’ where all elements of the building either play a structural purpose or is there for a climatic reason. Traditional and modern examples of climatic design, experience, and rules and guiding principles overlap and form the precedents 4 for the design (please refer to Appendix C for discussion question and answers, and Figures C-10 to C-13 for illustrations). The large roof overhangs for sunshading and rain protection, the narrow width of the building to allow cross ventilation, and shading provided by building blocks are the main precedent knowledge embodied in the examples of traditional Malay houses. Large louvers provide shading and allow wind penetrations just as in traditional window louvers. Scaled sectional drawings of the buildings are used to study graphically the design for shading by building elements as well as between buildings, rain protection and cross ventilations, and design judgements and decisions are made with the expert eye and mind, with no calculations.

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4 As discussed in Chapter 2, we noted that there is an area of overlap between established rules and principles, and reasoning with examples with the use of precedents.
Descriptions of design performance in environmental control

Akitek Tenggara described the design as, "Climatically, the design emphasises transparency and permeability in the spatial structure. The sheltering effect of the overhangs over the passageways creates an architecture of shade rather than an architecture of mass". It is also referred to as a very good example to demonstrate this new language of ‘line, shade and edge’ for the tropical region by the architect and the writer (Powell 1997), which is the “Line, Shade and Edge” paradigm we discussed in Chapter 1.

Various climatic aspects of Bishan ITE design has been described very positively in Line, edge and shade by Robert Powell (working closely with Akitek Tenggara for the book) as: “a modern architectural language for the tropics”; The curved roof has a wide overhang which gives protection from the rain and sun”; “aerolon-type louvers…. shield the external walls”; “every component either has a structural reason or is an essential climatic-controlling device”; referring to the open-to-sky auditorium or amphitheatre after the entrance, “The roof is a high curved steel frame with open sides, not entirely suitable for its users in a tropical thunderstorm but at other times it is the hub of the complex”; “The central "street" is reminiscent of Tay Kheng Soon’s ideas for Kampong Bugis DGP; it is high and narrow with overhanging roofs which effectively give shade throughout the day”; “Non-reflective landscape helps to cool the building” (Powell 1997, 123).

From the above, we note that the architect has great confidence in his prediction of the performance during design and making decision based on this confident judgement, and continues in believing in the design’s success after the building was completed. We also noted the observer/writer’s

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5 As quoted in Powell, 1997, 130.
6 Kampung Bugis Design Guide Plan (we will refer to this as the Bugis DGP in short) was a study and proposal for an ecological tropical urban design for the area of Kampong Bugis in the city of Singapore (K. S. Tay, R. Powell and B. H. Chua 1990).
confidence in his post-design evaluation of the building project. We will compare these confident statements of the architect, and the observer/writer of the design performances in environmental control with the findings on site.

**Building performance related to environmental control on site**

The observations and interview on site of users, and existing studies of the project mentioned above, reviewed that the solar control provision for the entire building was generally successful. However, there are certain areas of climatic inadequacy reported by users and normative checks.

*Protection from rain*

There is no wetting problem from the tropical rain for the enclosed spaces such as classrooms. Generally, users indicated that the covered spaces with exposed sides were the spaces they get wet often when rain was moderately heavy to very heavy (please refer to Appendix C for survey questions and report on findings on the problem of rain). This applies to the ‘open-to-sky auditorium’ or amphitheatre and the circulation spaces such as the open lift tower, staircase, bridges and corridors. The physical designs of these areas are indeed very ‘open’ or exposed on the sides and are susceptible to wind-carried-rain wetting the spaces and users, even though the rain protection devices such as roofs overhangs and louvers appear large in their coverage.
Protection from solar radiation

The study by Loo (1996) showed that most of the spaces within the building complex are well protected from solar radiation. Loo however found that the amphitheatre viewing area, and the landscaped street were not well protected from solar radiation. This is contrary to the intentions and comments about the building design for the amphitheatre and landscaped street, described above by the architect and observer/writer as providing good shade 'throughout the day'.

The shading louvers and roof overhangs on the two outermost facades were evaluated by P. Y. Loke as generally adequate or effective in shading direct solar radiation (Loke 2000). On the East facing façade, the roof overhang has an average effective shading of 82% and the horizontal louvers an average effective shading of 87%. This means they are only 18% to 13% ineffective, especially in the early hours of the day before 9am, which is not critical. The Western façade shows similar characteristic for both direct and indirect solar radiation shading, except that the ineffective direct solar shading happens at the end of the day before sunset, which is not critical. This means overall solar control is reasonably effective.

In addition to the above studies, a check was made with the SOL-ARIS shading analysis programme (Mahdavi and Lam 2000, 1994) for the typical corridor facing the East. The characteristic of the shading overhangs for the corridor was similar to the roof overhang of the East façade, but not as effective compared to the large horizontal louvers (average effective shading of direct and diffused solar radiation was 81% and 59% for the corridors compared to 85.5% and 67% for the louvers, respectively), meaning that the sun shading design could be improved.
Provision for ventilation

Even though sunshading is reasonably effective and design elements of roof, louvers and overhangs looks very shady, a certain proportion of users indicated feeling warm and expressed discomfort in the building complex. This was shown to be due to insufficient ventilation (air-movement) to offset the effects of solar radiation in certain parts the building (Loo 1996, 68). If the air-movement was generally higher to provide cooling to counter the built-up of heat, then the resultant comfort index will fall within the comfort zone. It can be observed on site that the design included mechanical fans in combination with the passive means of climatic modulation for the non-air-conditioned canteen and all the classrooms. In most of these interior spaces, owing to the effective sunshading, the marginal shortfall of air-movement can be helped with the mechanical fans to achieve the thermal comfort level. However the supplement of mechanical fans could not be applied to the main areas of high heat built-up and great shortfall of natural ventilation, which include the amphitheatre gallery and landscaped street, which form the main areas for human traffic. In these areas, the effectiveness for sun shading, and ventilation could be improved.

On the whole, the building complex showed very reasonable performance in climatic control in most areas. The rain and solar radiation protection provisions at the amphitheatre and circulation areas however are not adequate enough and could be improvement, contrary to the confident beliefs and comments of the architect and the observer/writer.

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7 This is in line with the normative guidelines of comfort zone by Olgyay and Olgyay (1963), and the Equatorial Comfort Index (ECI) of C. G. Webb described by Koenigsberger (et al. 1974). The ECI for Singapore is between 23.5 °C to 26.4 °C where a person will normally feel comfortable.
8 It is noted that for several of the top West-facing classrooms, extra mechanical fans are needed during the months of June to August as reported by users, because it can be uncomfortably warm.
9 C. C. Loo’s study shows a proportion of 40% of users indicating uncomfortable (including 10% very uncomfortable), and 85% warm (including 10% very warm) in the overall complex (Loo 1996, 80). This will therefore mean that the landscaped street and the amphitheatre, which together with the corridors, form the main circulation area that gives the user the feeling of discomfort.
Analysing the findings for heuristics, biases and errors

Some observations on the characteristic of the design process

We have noted above that the architect is sincere and dedicated, and of sound mind to achieve his objective of providing the best climatic control with the design for maximum shade of sun and rain, and cross ventilation. The overall design with large overhangs, louvers, and building blocks shading each other appears very promising in the design drawings and proposal, and was described or judged favourably as a good example of climatic design by the architect and others. The site study, user interviews, measurements and calculations show certain high level of overall effectiveness and success in the heuristic design approach of the architect. But they also revealed certain levels of inadequacy and causes of discomfort in certain areas. There is a lot of uncertainty in the combination of sun, rain, air-movement, and other factors to consider in design for a comfort level, and the performance of design decided based on heuristic judgement, sometimes far short in actual performance in some areas. Even though the designer has high confidence that his building is a good example demonstrating the paradigmatic expression of the “Line, Edge and Shade” paradigm for tropical architecture, errors exist. The rain and heat protection provisions at the amphitheatre and circulation areas are not adequate enough, and could be improved. We will examine the precedent entities and properties used as heuristics below and use them to relate to the theories of heuristics and biases discussed in Chapter 4.
Precedent entities and properties used as heuristics

Some of the main precedent examples referred to by the architect were from the traditional village house, the Singapore Conference Hall and Trade Union House by Lim Chong Keat, and the Scouts Headquarters by E.J. Seow. The following precedent entities were used for the design of Bishan ITE:

1. Large roof overhangs
2. Porous facades
3. Large louvers
4. Layouts on site

From the precedent examples, these entities were believed by the architect to possess certain properties that provided various operations and performances in environmental control, and were used as guidelines for the design of Bishan ITE. The key respective properties assumed and referred to guide the design were:

1. Large roof overhangs has sheltering property and offers effective protection from rain and solar radiation.
2. Porous facades allow wind to permeate and offer effective ventilation.
3. Large louvers have shading property and offers effective protection from solar radiation. They also allow wind to permeate and offer effective ventilation for non-air-conditioned spaces.
4. Certain layouts of building on site have the property of self-shading and offer protection from solar radiation. In the case of the layout of two building blocks with a landscaped space in between, the buildings

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10 From the interview with Akitek Tenggara (see Appendix C) and the statements Akitek Tenggara made about the thinking behind the design of this and other projects in Powell (1997).

11 Ibid.
offer shade and protect the space from solar radiation throughout the day.

These properties were what the architect talked about, believed in and used in the design thinking process of the Bishan ITE project. We noted above that this approach has yielded much success. But there were also some errors of unwarranted confidence in the performance of certain areas of design. That meant the heuristic judgements and decisions for some parts of the building design were not accurate or effective. These will be examined against the theories heuristics and *biases* to see which heuristics and *biases* may be operative in the design process that produced the unwarranted confidence. We will first examine the design problem with the theory on *representativeness*.

**Biases due to representativeness - ‘A’ similar to ‘B’ therefore**

From the architect’s description of design precedents for climatic control, it is clear that precedent entities such as large roof overhangs, shading devices, permeability of building were used in guiding the design. Since no computational methods were used, the judgements were made based on how the design of each new building element appeared to perform in the similar way as the precedent entities. These could be understood as working with the *representativeness* under uncertainty discussed in Chapter 4. The designs employing this heuristic for sunshading devices, and ventilation provisions were largely very successful, except for the high built-up of heat in the landscaped street and amphitheatre areas, and the rain problem at the amphitheatre and circulation areas.

Let us examine the errors in relation to *representativeness* and *biases*. In these areas of errors, the large roof and closeness of building blocks
resemble or appear representative of adequate sun shading, and openness for natural ventilation and cooling. The large roof overhang is also representative of protection from rain. However, the confidence in each instance was unwarranted. These could be understood as judgements that suffered from representativeness biases, termed by Tversky and Kahneman as the illusion of validity discussed earlier.

The unwarranted confidence, produced by similarity or quality of match is analogous to the example of Steve discussed in Chapter 4. There is unwarranted confidence in his occupation as a librarian because the description of him fits or matches that of the stereotype of librarian, which according to Tversky and Kahneman will prevail even if the description was scanty, unreliable, or outdated. In the same sense each of the design elements here was representative of certain performances in the precedent cases that formed the design guideline. Thus each of these areas of over-confidence could be understood with the explanation of the illusion of validity.

**Biases due to availability - ‘A’ is easier to imagine therefore**

In Chapter 4 we also discussed that availability or ease of recall and imaginability in the mind affects judgement. The availability increases with familiarity, fame, and salience, where each affects the ease of registering something in memory and the retrieval of it. We discussed that hypothetically and analogically, when judging the level of success in the performance of a design by a famous architect, it is easier to retrieve instance of him succeeding, and therefore judgement of success will tend to be on the high side (just as risk is on the high side for the plane accident because plane accidents are dramatic, better remembered, recalled and imagined).

In the case study building project, descriptions of the performance of the building tended to be on the higher side compared to what is happening on
site for the roof over the amphitheatre and landscaped street. The amphitheatre was evaluated and described as not doing well only in thunderstorms, but in fact it does not do well in moderately heavy rains, and is low in thermal comfort level. The landscaped street in-between buildings was described with reference to the highly esteemed example of Bugis DGP, describing it as high and narrow with overhanging roofs which effectively provided ‘shade throughout the day’. In fact it was shown to be very high in solar radiation most parts of the day, and not in ‘shade throughout the day’ as believed and described by the writer. Because of the fame and high regard for the designer, it was easier to recall the famous example of Bugis DGP that he mentioned\textsuperscript{12}, and to imagine the success of the project. The observer/writer’s unwarranted confidence or overestimation in judgement could be understood as owing to \textit{biases} associated with \textit{availability}, termed by Tversky and Kahneman (Judgement under uncertainty, 1982) as \textit{biases due to imaginability}.

The implication of this is important. The writer or observer and the reader, goes away with the beliefs that the amphitheatre and landscaped street have certain levels of high climatic performances. These may set a precedent for future designs, and can lead to further errors of unwarranted confidence.

\section*{Limitations of the case study to establish other biases}

It is a limitation of this case study to establish if anchoring (Tversky and Kahneman, Judgement under uncertainty, 1982) or contraction \textit{biases} (Poulton 1989), discussed in Chapter 4, were operative because the magnitudes of precedent design guidelines and starting values of each design

\textsuperscript{12} It is important to note here that the Bugis DGP was not yet implemented and realised as real buildings, but yet the observer/writer had confidence to use it as an example for judging the Bishan ITE built project.
element cannot be clearly established through the interviews and materials collected.

The designer's choice of metallic materials for the shading devices is puzzling because metallic materials heat up quickly and re-radiate heat, and is also glaring. It is strange that the designer thought that metallic materials are more suitable because it has low heat capacity (store little heat) and lose heat quickly. One possibility could be that the designer simply loves the metallic materials because they fit his ideological claim that all design should be forward looking and not be regressive. However it is beyond the scope of this study to investigate the effects on decision owing to ideological desires (implicit or explicit motivational factors) that conflict with design for climatic environmental control.¹³

¹³ There is a possibility where ideological motivation results in self-deception. Please refer to Self-deception (Herbert Fingarette 1969), Multiple self (Jon Elster, ed. 1986), and, Self-deception and paradoxes of rationality (Jean-Pierre Dupuy 1998), which offer many interesting discussions on self-deception and paradoxes. There could also be another hypothesis that time pressure and stress forces heavier weighting on various values or criteria of importance, in this instance his preferred ideology (Edland and Svenson 1993, 31). Please refer to Svenson, and Maule (1993), Time pressure and stress in human judgement and decision-making.
In this case study we discussed and observed several main points. The overall effectiveness of design based on precedent entities and properties such as large roof overhangs, louvers, shading with building blocks and permeability for ventilation could be understood as successful employment of representativeness to solve design problems under uncertainty. Some errors did occur and could be understood with the theory of biases associated with representativeness. Some errors in the observer/writer's judgement of climatic performance of the design were also detected and could be understood with the theory of availability and its associated biases. In the following chapter, we will model a minimal cognitive design process of the problem based on the case study, the theory of heuristics and biases discussed, a conceptual system and a framework of architectural knowledge discussed.
CHAPTER 6

A MODEL OF DESIGN THINKING WITH HEURISTIC BIASES

Theoretical model to understand how and why errors of judgement and decision occur: With the case of tropical architecture

In this chapter, we will use the key elements in the heuristic process discussed in the analysis of the problems of errors of designs in the case study, in the previous chapter, and develop a cognitive theoretical model to represent a minimal cognitive structure in the design thinking process with this specific problem of heuristics and biases.

In the previous chapters, we discussed that precedents were used to guide in the visual-mental judgement of the degrees of effectiveness of the climatic control in designs. The designer used representativeness to judge or predict performance by similarity or match so as to make quick and efficient decisions accordingly, which were not accurate all the time. There were some mistakes observed in the case study, and these could be understood as the affects of the illusion of validity. The observer and writer viewed the project (building and/or illustrations) also by the eye without the aid of normative quantitative calculations. He was overconfident in his prediction or judgement of the performance of some areas of design, and these could be
understood as the affects of biases in availability with the ease of recall and imaginability triggered by the fame of the architect.

Elements in the heuristic design process

From the preliminary case study and discussion on tropical architecture in Chapters 1 and 2, and the detailed case study of a specific building project in Chapter 5, we can identify several elements in the design process, while using precedents as heuristics for judgement and decision-making.

We identified entities and properties of the precedents used. Each entity is a form or morphology of certain property of operation and performance. These forms affords certain operations like sheltering for instance, and in turn affords performances or benefits such as protection from rain or solar radiation.

We also observed from the descriptions of the design process that there were the processes of learning, and recalling of precedents, and confidence in the properties of the precedents. This involves the source or origin of precedents of whether they were authoritative, as in the example of time tested traditional village housing models, and whether they have shown to work well for various properties they exhibited. There is also the element of desired performance, requirements, or goals that has become norms in the design vocabulary, such as the requirements of protection from rain and solar radiation, related to the higher norm of human comfort and convenience.

Assumptions and limitations of discussion

We limit the discussions in the modelling to belief statements made by the architect and the writer in the case study of the specific project in the last
chapter. We assume the elements referred are the main elements in their design thinking influencing their judgement and decisions.

In the reference to traditional examples for instance, the architect made the belief statements about the comfort of users with limited elements of design. He believed the time-tested precedents show that human comfort can be achieved through protection from the sun and rain, by providing large roof overhangs, porosity in the building walls for ventilation, and appropriate building orientation. We noted from environmental engineering theories (e.g. Fanger 1970) that thermal comfort is achieved through a combination of interrelated factors (as discussed in Chapter 1). We assume that in the traditional precedents, the combinations of factors must have existed for the users to experience thermal comfort. The combinations of these factors are assumed implicit or transparent to the designer.

Also for practical reasons, the architect can control mainly those aspects he referred to for providing human comfort for non-air-conditioned spaces, which are passive means. Therefore, we have reductive statements in the modelling, such as, “If the room is shaded from solar radiation with sun-shading louvers, THEN thermal comfort is achievable”. We are not saying that the other factors are not involved for the provision of thermal comfort, but they remain implicit in the precedents and the thoughts of the designer.

The reduction also allows us to isolate elements for discussion, to pinpoint examples of sources of biases and errors due to representativeness and availability. We are not saying that there are no other causes of biases and errors.

Cognitive structure in design thinking

In this section we will first describe a cognitive structure to represent the design thinking in general. We will then apply the theoretical model to the
problem to discuss what happened and how representativeness and availability used in judgement result in seemingly irrational actions.

Normative and descriptive thinking

The study of choice or decision encompasses both normative and descriptive questions. Kahneman and Tversky (1986, 194) noted: "The normative analysis is concerned with the nature of rationality and the logic of decision making. The descriptive analysis, in contrast, is concerned with people's beliefs and preferences as they are, not as they should be. The tension between normative and descriptive considerations characterises much of the study of judgement and choice". We will model the cognitive structure of the climatic design process reflecting the interaction of the normative and descriptive considerations.

Representing the structure of thinking

The actual internal design thinking process in the mind of the designer is not totally obvious, but can to a certain degree be described and understood with a model based on the external thinking process, observed through the descriptive and prescriptive (normative) statements made by the designer. Based on the theory of action and evaluation of action¹ Tzonis et al. (1978) derived a representation of a minimal necessary cognitive structure, termed the Kernel of Conceptual System. This is a primitive universal organization that is common to any thinking process including design thinking. Further to this, Tzonis developed a framework for representing architectural knowledge with the interrelated concepts of performance, operation, and

¹ Refer to von Wright 1968 and Rescher 1966 for more information on norm, action, and the relationship of descriptive statements and prescriptive command.
morphology in a context (Tzonis 1992) (we will refer to this as the Performance-Operation-Morphology Framework).

A kernel of conceptual system

The Kernel of Conceptual System developed by Tzonis et al. (1978, 5) represents a minimal cognitive structure applicable to the design thinking process with observed inference\(^2\) of prescriptive statements mixed with descriptive statements. A descriptive statement describes attributes of a state of design as what 'is' factual, for example ‘window facing the Western solar radiation’ and is evaluated by whether it is true or false. A prescriptive statement is a deontic statement of 'ought to' for an action or command for an action or a plan for action that brings about a state or change of state, and is also termed as design directives. An example of a prescriptive statement is ‘ought to provide louvers to shade windows’, and is evaluated for its ‘validity’. These are all observable from the verbal statements and/or graphic drawings of the designers. A norm or set of norms generates various design directives (Figure 6-1). Tzonis and Oorschot (1987) have categorised five major groups of architectural norms. Norms are pragmatic programmes, goals, needs, objectives, or standards of practices of life. (Please see Appendix D for 5 main categories of norms and hierarchy of norms in the practice of architecture.)

The kernel of design thinking contains two branches: the deontic and the factual. Norms generate design directives or plans, in the deontic branch (Figure 6-1). A fact is a descriptive statement with the 'IF-THEN' implications that interact with the prescriptive statements. A backing (from empirical examples) supports a fact, and the truth-value of the backing is

\(^2\) This is based on the concept of Heterogeneous Command Inference (Rescher 1966, 99). Inference of a command (or directive) is made from premises that contain a mixture of descriptive and prescriptive statements.
reinforced by *base* information or beliefs (the authority or trustworthiness of the information or beliefs).

**Figure 6-1**

*Kernel of Conceptual System with Base and Backing*  
(Tzonis et al. 1978)

Below is an example of a set of related *prescriptive* and *descriptive statements* for a *Kernel of Conceptual System* representing pre-parametric and qualitative judgement and decision-making in the design for environmental control:

**Norm:** ‘reduction of heat for thermal comfort for people in a room’

**Directive:** ‘provide sun-shading louvers’

**Fact:** ‘IF the room is shaded from solar radiation with sun-shading louvers, THEN reduction of heat for thermal comfort is achievable’

**Backging:** ‘a precedent case showed that sun-shading louvers shade and keep the room heat level low within conditions of thermal comfort’

**Base:** ‘the precedent is a trustworthy time-tested case’
A framework of architectural knowledge

The concepts and relationships of *performance, operation, and morphology* with a *context* in the *Performance-Operation-Morphology Framework* have been used to examine architectural design thinking (Zandi-Nia 1992, Fang 1993, Li 1993, Ye 1994, and Jeng 1995) in various situations or *contexts*. Tzonis (1992, 147) has demonstrated this framework of representing knowledge using a case example of Unite d’Habitation, where Le Corbusier mapped by analogy (discussed in Chapter 4) the relationship and structure various precedent entities and properties of ‘hut’, ‘ship’, and ‘bottle-rack’ unto the new apartment building design with the three concepts of *performance, operation and morphology*. We will illustrate the three concepts discussed by Tzonis (op. cit.) applied in the *context* of preparametric and qualitative design for environmental control in the tropical zone as follows:

*Performance* - refers to the conditions a prospective building is intended to bring about, or the degree to which a scheme of a building brings these conditions about. The *performance* (P) for example can be ‘the thermal comfort of users in the urban tropical environment’ or the condition of ‘not being wet by the rain’.

*Operation* - refers to the processes of use of a building, and the role of form in these processes. For example the *operation* (O) or role of a roof is ‘shielding solar radiation and rain’.

*Morphology* - refers to the formal aspects of a building or urban design. For example the ‘form of the roof’ or the physical configuration ‘of the space between two buildings’ is the *morphology* (M).

\(^3\) *Performance* can also refer to the energy saving offered by the design.
The Performance-Operation-Morphology Framework can be used to discuss the relation of prescriptive statements in the deontic (or normative) structure, or it can be used to understand the relationship of descriptive statements.

Relating the framework of architectural knowledge to the conceptual system

Performance-Operation-Morphology Normative Structure

Relating to the deontic or normative structure of the Kernel of Conceptual System, the desired performance (Pd) of a building design is the highest norm (goal) generating the related desired operation(s) (Od) and/or in-turn the desired morphology (Md) required for bringing about the performance (Pd) (Figure 6-2). For example, ‘heat reduction for thermal comfort’ (norm 1N) generates the directive (1D) of the operation of ‘shading solar radiation’, and that in turn becomes a norm (2N) that generates the directive (2D) for the morphology of ‘horizontal shading louvers’. Let us call this systemic structure of logical relationship Performance-Operation-Morphology Normative Structure (Figure 6-2).

It is also possible for desired performance (Pd) to generate a directive for desired morphology (Md) bypassing the related operation depending on the fact referred to or recalled in this deontic link. In the earlier example, the norm of ‘reduction of heat for thermal comfort for people in a room’ generated a directive to ‘provide sun-shading louvers’, with the fact that ‘IF the room is shielded from solar radiation with sun-shading louvers, THEN reduction of heat for thermal comfort is achievable’. The operation (Of) of shading is in a descriptive sense (more of a belief or degree of truth rather than a command or ought to). It can also be omitted if the fact is ‘IF sun-shading louvers are provided, THEN heat reduction for thermal comfort is
achievable’. (The fact is a belief statement based on a precedent that is assumed reliable, and may or may not be accurate in the actual built situation, but is used for generating the directive that ‘ought to’ follow a certain norm (goal). The directive when implemented in an actual building may not yield the built performance that equals the desired performance (Pd).)

Figure 6-2
A Performance-Operation-Morphology Normative Structure in a deontic chain

Morphology-Operation-Performance Belief Structure

In the factual or descriptive branch of the Kernel of Conceptual System, Performance-Operation-Morphology Frameworks can be found in the fact, ‘IF-THEN’ statements, and in the backing statements. For example, ‘IF the room is shaded from solar radiation with sun-shading louvers, THEN
thermal comfort is achievable’ has the relationship: morphology (Mf) of ‘sun-shading devices’ believed to lead to operation (Of) of ‘providing shade’, which in turn is believed to lead to performance (Pf) of ‘reduction of heat for thermal comfort’. And this has the backing ‘belief’ or ‘confidence of the truth’ that in the precedents, it has been shown that morphology (Mp) brings about operation (Op) brings about performance (Pp). The base reinforces this trustworthiness. In the factual descriptive statements there is a belief structure of the relationship of morphology, operation, and performance, and we shall call it Morphology-Operation-Performance Belief Structure (Figure 6-3).

Similarly, certain morphology can also be believed will lead to a performance without reference to the related operation. For example a fact statement can be ‘IF big roof overhang, THEN thermal comfort’.

Learning and remembering precedents

In the practice of design, precedents are referred for heuristic judgement (and in turn decision-making). Precedents are learnt and registered in
memory from various sources, including lessons in school, books, magazines, experiences of actual projects, and case reports. Each architectural precedent is registered in memory for its performance related to certain morphology and operation. A descriptive statement that ‘large roof overhangs of the indigenous houses protected the inhabitants from the hot solar radiation and the rain, and keep them comfortable’ has a precedent morphology-operation-performance (Mp-Op-Pp) belief structure, and that ‘large roof overhangs provide thermal comfort’ has a structure of precedent morphology-performance (Mp-Pp) belief structure. The corresponding structures stored in memory will be ‘Mm-OM-Pm’ and ‘Mm-Pm’ (Figure 6-4), with certain degrees of belief. The recall of these precedents to guide judgement will be based on the search and match of the pattern (representativeness) of the requirement with these structures. Simon (1986, 109) described the expert as having the ability to exploit knowledge gained through experience to solve problem rapidly, through a search-like process and the sudden recognition of familiar patterns. Figure 6-4 serves to represent a limited learning-registering, memory and recall sequence.

More salient, current, or dramatic facts are registered better in the human memory system (e.g., Ashcraft 1998; Anderson 1983; Minsky 1986; Tversky and Kahneman 1982c) and therefore better retrieved or more available when availability are employed for judgement and decision-making. Projects and successes by famous architects are better remembered (registered and retrieved), then less famous architects. Distinctive and emphasised qualities of the indigenous houses are better remembered. And conversely it is easier to recall these items. Architects work graphically and therefore remember and recall better graphically, especially for pre-parametric and qualitative thinking of his work. Distinctive morphology is also better remembered than

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* Memory here refers to both working and long-term memory for retention of information. Learning, registering, recall, and imagining are in the working memory or short-term memory, which may be transferred into the long-term memory for long-term storage. For more information of differentiation of types of memory and their relationships, refer to Ashcraft (1998), and Squire and Kandel (1999). Also refer to Anderson (1983) who discussed the relationship of declarative memory, production memory, and working memory in a larger cognitive application with his model for adaptive control of thoughts termed ACT* (pronounced as “ACT Star”).

127
calculations and numbers, and more easily recalled and used in his imagination for his designing work.

In the process of making a judgement, estimates of performance (Pf) from operation (Of) and from morphology (Mf) are made with reference to precedents, by comparing and matching (representativeness) with remembered precedents, and those that are easier recalled and imagined (availability)\(^5\) (Figure 6-4).

Figure 6-4
A limited learning-registering, memory, and recall sequence

Representing the problem of heuristics and biases in design thinking in the case of tropical architecture

The Kernel of Conceptual System and Performance-Operation-Morphology Framework discussed above are now used to discuss the problem with the heuristic design judgement and decision-making process with reference to the large roof over the amphitheatre, and the landscaped street between

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\(^5\) Judgements are also made by reference to anchors, and making estimated adjustment from them. This has been discussed earlier as being beyond the limits of this study.
buildings, in the case study in Chapter 5. First, we will model the problem of errors due to biases in the use of representativeness making prediction or judgement and decision. Then we will model the problem of errors due to biases of availability due to ease of recall and imaginability in diagnostic descriptions of building designs by the observer/writer, that may affect future design thinking.

Model relating to representativeness and illusions of validity

In the case study of the specific building project, the decision (or command leading to an act) to build the large roof over the amphitheatre was based on the precedent of the indigenous architecture. Let us break the analysis into 2 stages:

Stage 1 – Learning-registering, memory and recall sequence for, ‘large roof’, ‘shielding solar radiation and rain’ and ‘climatic comfort’\(^6\) using representativeness with associated bias in judgement

Stage 2 – Kernel of Conceptual System for ‘climatic comfort’ performance, leading to a directive for a particular morphology of the roof over the amphitheatre with error owing to an illusion of validity

Stage 1 – Learning-registering, memory, and recall

The architect mentioned that indigenous architecture, with large roof overhangs, was used as an example to emulate and design Bishan ITE. It was

\(^6\) As qualified in the beginning of this chapter, this is a belief statement of the architect, based on precedents with other implicit climatic conditions for human comfort, and does not mean that other climatic factors were not considered for comfort.
learnt and committed to memory that ‘large roof overhang that shielded solar radiation and rain, gave climatic comfort’. In Stage 1, this *morphology-operation-performance belief structure* was committed to memory, meaning ‘large roof overhang’ believed leads to ‘climatic comfort’. (Figure 6-5)

### Figure 6-5
**Stage 1 – Learning-registering, memory, and recall sequence for ‘climatic comfort’ and ‘large roof overhang’ with representativeness and biases**

<table>
<thead>
<tr>
<th>Learning &amp; Registering</th>
<th>M-O-P belief structure</th>
<th>Long-term Memory</th>
<th>Match / Fit representativeness</th>
<th>Recall, Imagining &amp; Judging</th>
</tr>
</thead>
</table>
| From example of the indigenous ‘large roof overhang that shielded solar radiation and rain, gave climatic comfort’ | \[ M_p = \text{'large roof'} \]  
\[ O_p = \text{'shielding solar radiation + rain'} \]  
\[ P_p = \text{'climatic comfort'} \] | \[ M_{m-opm-pm} \] or \[ M_{m-opm} \] | \[ M_{o-p} \text{ structure required match} \] \[ M_{m-opm-pm} \]  
Representativeness caused illusion or bias affecting descriptive-judgement belief or fact | ‘IF large roof overhang, THEN shield solar radiation + rain’, THEN climatic comfort'  
\[ M_{m-opm-pm} \text{ or } M_{of-pf} \]  
\[ M_{p-f} \] | "Descriptive statements, fact" |

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**Stage 2 – Kernel of Conceptual System**

In the design process, the norm or requirement of *performance* (Pd) for a certain degree of ‘climatic comfort’ for the amphitheatre triggered a match or fit (*representativeness*) to recall from the long-term memory a precedent. What was recalled of *morphology-operation-performance* (Mm-Om-Pm)
belief structure from memory\textsuperscript{7} was used as a 'pre-parametric and qualitative precedent' to formulate a descriptive statement (with estimation or judgement accompanied by certain degree of belief) or fact:

'IF large roof overhang (of certain morphology, Mf), THEN shield solar radiation + rain (of certain operation, Of), THEN climatic comfort (of certain performance, Pf)'

Or

'IF large roof overhang (of certain morphology, Mf), THEN climatic comfort (of certain performance, Pf)'

In Stage 2, the norm or design performance (Pd) in the Kernel of Conceptual System generates a directive for particular roof morphology (Md), over the amphitheatre based on the fact above (Figure 6-6).

The designer thought and sketched a ‘roof with large over hangs’ over the amphitheatre to match (representative of or fit) that of the ‘largeness’ of the precedent example so as also to match the performance. In Chapter 5 we discussed that errors occurred and that they could be understood to be due to a biases or illusions of validity associated with the use of representativeness, according to the theory of heuristics and biases by Tversky and Kahneman (1982b). The unwarranted confidence in prediction will lead to ‘invalid’ decision or choice, i.e. ‘systematic error’. In this case, the performance-operation-morphology structure of design requirement, matched conceptually and graphically the precedent recalled (Figure 6-6).

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\textsuperscript{7} Memory can also be extended to an external storage of information like the designer’s previous sketches, photographs, and books that he refers to. At the point of judging the effectiveness of the roof for shielding of solar radiation and rain, and climatic comfort performance a designer can be comparing to a picture or drawing of precedence project, or he can be referring to ‘picture’ in the mind.
This match or representativeness gave the unwarranted confidence of judgement in the descriptive statement or fact. So if morphology of design requirement matches morphology believed in fact then the design performance was supposed will be in order when built. Systematically, a norm (goal) for a certain degree of performance (Pd) should generate a corresponding morphology (Md) of a certain physical attribute, which when built will perform as expected. In the case study project the roof performance fell short of the fact believed, because there was a bias due to representativeness.
Illusion of validity

According to Rescher (1966) for Heterogeneous Command Inference, where command means norms here, “A command inference that infers a command conclusion from premises containing a mixture of commands and assertoric statements can be ‘valid’ only if the command conclusion must be terminated whenever (i.e., in any possible world in which) all the command premises are terminated and all of the assertoric premises are true”. ‘Assertoric premises’ here refers to the descriptive fact statement, and it must be true for the directive to be ‘valid’. 

Desired Performance (Pd) generates a corresponding desired morphology (Md), based on the fact that was not accurately judged (wrongly believed with overconfidence and not true). If the designer decides on this particular morphology (Md), then it is not ‘valid’. It will not perform as desired. The design directive generated by the norm was not ‘valid’. The case on site showed that the amphitheatre was not adequately shielded from the rain and solar radiation, and it was not climatically comfortable as intended or judged and decided. The decision or action was not ‘valid’ because of the overconfidence in the fact owing to a bias in representativeness, termed by Kahneman and Tversky as the illusion of validity. This heuristic judgement has two components:

1. Representativeness of morphology in ‘largeness of roof overhang’ (how desired morphology (Md) matched morphology in the fact (Mf) which was derived from the memory of the precedent), and

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8 ‘Valid’ or ‘validity’ is used in the legal sense (Wright 1963, 194-199), and the ‘validity’ of the act of issuing or generating a directive means the legality of the act of issuing this directive.

9 Illusion of validity (Kahneman and Tversky 1982) is understood here as an illusion in judgement affecting the truth in the descriptive belief, that was followed by a normative decision that is not ‘valid’. This is consistent with the framework for studying judgement and decision by Kahneman and Tversky (1984), where they noted, “The tension between normative and descriptive considerations characterises much of the study of judgement and choice”.

133
2. Representativeness of operation in ‘shielding of solar radiation and rain’ (how desired operation (Od) matched operation in the fact (Of) which was derived from the memory of the precedent).

In the pre-parametric and qualitative design process, judgement is made without normative quantitative calculation. The assessment or prediction is done with the mind and eyes, by comparing graphically and visually with the precedent. Both the representativeness of morphology and operation (i.e. that they looked very similar to the precedent of the indigenous roof form and operation) could cause the overconfidence in assessing what was sketched for the roof as suitable to produce adequate outcomes. It seemed that the judgement of the operation should trigger a closer look at whether the form works. But it could suffer the same extent of representativeness bias as the morphology in the belief that it will work, overconfident on the positive outcomes in operation and performance.

The assessment could also miss the component of assessing operation, as if there is no difference because of the same extent of bias. If in comparing the desired morphology with that of the fact of the ‘largeness of roof overhang’, there was a bias of overconfidence that the design will yield similar a certain operation, then there will be a corresponding overconfidence that the design will perform to the level of the desired performance. In both cases, desired performance generating desired morphology suffers from the illusion of validity (Tversky and Kahneman 1982), and the rational architect appears irrational in his action.

Model relating to availability and biases due to imaginability

In the case project, we noted that a writer (R. Powell), as an observer, assessed the project and wrote statements of overconfidence about the
landscaped street between the buildings. He stated that the street “is reminiscent of Tay Kheng Soon’s ideas for Kampong Bugis DGP; it is high and narrow with overhanging roofs which effectively give shade throughout the day”\(^\text{10}\), meaning good climatic \textit{performance} (protection from the solar radiation) of the design throughout the day. It is noted that for the observer/writer, it does lead to a command for action for something that will be built on site. But it leads to the action of writing about the \textit{performance} of a certain part of a project that can become a precedent for future designers. This interest in this writer as a ‘design observer’ is also important because if the observer is another designer\(^\text{11}\) who judges the degree of success of design \textit{performance}, he will remember the \textit{Performance-Operation-Morphology Normative Structure} of this project as a precedent \textit{Morphology-Operation-Performance Belief Structure} to guide his future judgements and decision-making. The accuracy, or lack-of accuracy, in this heuristic process of judgement is therefore important, and will be examined similarly in two stages:

\begin{itemize}
\item Stage 1 – Learning, registering in memory, and recall and imagining sequence for the observer making judgement with \textit{availability} and associated \textit{biases}.
\item Stage 2 – \textit{Morphology-Operation-Performance Belief Structure}; \textit{descriptive statements} by the observer affected by \textit{biases} of \textit{imaginability} associated with \textit{availability} in his judgement process.
\end{itemize}

\textbf{Stage 1 – Learning-registering, memory, and recall and imagining}

\textit{Availability} is increased with familiarity, fame, and salience. The fact that the architect is famous, it is easier to recall success and many instances of buildings or parts of buildings that were said to have high \textit{performance} in

\textsuperscript{10} As discussed in Chapter 3, page 6, quoting Powell (1997).
\textsuperscript{11} Incidentally, the writer, R. Powell is also an architect who practices design.
various media. As discussed in the case study in Chapter 5, there was overconfidence in the observer/writer's judgement of the climatic performance of the 'street in-between buildings' by the observer/writer. There is overconfidence in the performance-operation-morphology structure in memory, and in the fact (Figure 6-7).

The overconfidence in the precedent was caused by the availability due to salience of success and fame of the architect. There is overconfidence in the fact that: 'IF street between buildings (of certain morphology Mf), THEN shielding of solar radiation (of certain operation Of), THEN protection, from

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12 As discussed in Chapter 5, the Bugis DGP was not yet implemented and realised as real buildings, and yet the observer/writer had confidence to use it as an example for judging the Bishan ITE built project.
solar radiation whole day (of certain degree of climatic performance Pf). According to the theory of Tversky and Kahneman on availability and biases (discussed in Chapter 4), it is easier to imagine that the design by the famous architect works successfully, and therefore it is judged more successfully. This is the problem of the biases of imaginability that is associated with judgement with availability.

Stage 2 – Morphology-Operation-Performance Belief Structure

In the case of the observer/writer, the observed morphology (Mo) corresponds with the designed morphology (Md), and the descriptive morphology (Mf). In morphology-operation-performance structure of the fact, the operation (Of) and performance (Pf) are believed to be happening for the whole day. By looking at the morphology of the design, which matches the morphology (Mf) in the fact, the writer concludes that it performs as what he believed in the fact. But this was not the case on site for the operation and performance of the building design at the landscaped street between buildings (Figure 6-8).

The overconfidence in the fact ‘IF street in-between buildings, THEN shielding from solar radiation. THEN protection from solar radiation whole day’ affected the observer/writer in his conclusion that the landscaped street in Bishan ITE was effective climatically (from solar radiation) the whole day, when in fact it was not. During the observation, it could also be judged with the believed descriptive that ‘IF morphology Mf, THEN performance Pf’. In both cases the net result is that if the observer is a designer, he can transfer this error in judgement (the overconfidence in the fact ‘Mf-Of-Pf’ or ‘Mf-Pf’ belief structure) into guiding his judgement and decision-making for his future design, and this can make his design action ‘invalid’.
Beliefs in facts, biases, and rationality

From the analysis design thinking process, we see that the designer’s decision was not ‘valid’ and his action seemed ‘irrational’. The architect may be mistaken as making ‘irrational’ actions or may seemed ‘irrational’, when his design fails.

The question of rationality is an interesting topic debated by philosophers throughout the ages. We have discussed earlier that man does not fully know all factors of a problem or analyse all possibility and probability before
making a perfect decision based on total maximisation. He uses minimal rationality (Christopher Cherniak 1986) or bounded rationality (Simon 1972, 1986, 105). In a sense the architect (the actor who has a plan for action, or a design for certain performances) in the case study here is rational, but suffered an illusions, made mistakes, and seemed 'irrational'.

In discussing rationality in the case of Hitler, Simon (1986, 97) observed: “if we were to suspend disbelief for a moment and accept his ‘facts’ as true, much of the Nazi program would be quite consistent with goals of security for the German nation or even of welfare for the German people”. And he went on to note that we could not dismiss Hitler as a madman because his prose met general standards of reason. Simon (1986, 99) concludes by saying: “Reason was not, could not have been, our principal shield against Nazism. Our principal shield was contrary factual beliefs and values”. This is similar to the analysis of the case project above where the architect could not be dismissed as ‘irrational’, i.e. he is rational, but one could question his factual beliefs.

There is also another possibility that this was a case of self-deception where the designer wanted so much to believe that his design worked and looked matching enough with his precedent entities and properties that he deceived himself. This is especially so because he wanted so much to arrive at a modern aesthetic, modelled after the indigenous precedents of climatic control with large roof overhangs, etc. The ideological value or aesthetic preference and goal could have interfered with his judgement of the design in climatic performance and he deceived himself. This paradox is also interesting, but lies beyond the discussion of this study. 13

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13 Please refer to Self-deception (Herbert Fingarette 1969), Multiple self (Jon Elster, ed. 1986), and, Self-deception and paradoxes of rationality (Jean-Pierre Dupuy 1998), which offer many interesting discussion on self-deception and paradoxes. There could also be another hypothesis that time pressure and stress forces heavier weighting on various values or criteria of importance, in this instance his preferred ideology (Edland and Svenson 1993, 31). Please refer to Svenson, and Maule (1993), Time pressure and stress in human judgement and decision-making.
We have represented the problem of judgement and decision-making in the pre-parametric and qualitative mode in the case of tropical architecture with a conceptual system and framework for architectural knowledge. We discussed how *biases* were linked with the seemingly irrational decision of the architect who is most of the time a rational actor. Heuristics used in judgement and decision-making does yield fast, efficient, and reasonably effective results, but not all the time. The key problems of errors in judgement and decision lie in the disproportionate beliefs, illusions or *biases* in the facts based on precedents. We identified two heuristics, their associated *biases* that can cause the errors in the case of tropical architecture, and showed how they are interrelated in a model of minimal cognitive structure and framework for architectural knowledge for design thinking. We illustrated two cognitive *biases* at work:

1. *Illusion of validity* related to *representativeness*, and

2. *Biases* due to *imaginability* related to *availability*.

Having represented the problem with a theoretical model and seen where the over-confidence in judgement occurred and are linked with various elements in the design thinking process, we can now examine a possible way to reduce the impact of *biases* in the following chapter.
CHAPTER 7

DEBIASING

A framework for debiasing illusions in design thinking

In this chapter we will discuss various therapeutic possibilities suggested by various writers, and examine one possible strategy for debiasing illusions in tropical design, in relation to the understanding and theoretical model in the previous chapter. We will then expand the cognitive theoretical model we proposed in the last chapter to include this strategy of debiasing, so as to arrive at a model for improvement in design thinking that address the problem of cognitive biases.

We will first look generally at what several writers have discussed about debiasing to improve judgement and decision-making. We will then discuss one possibility in more detail in relation to the case of tropical architecture and the cognitive theoretical model we proposed in the last chapter. From this discussion we will arrive at a theoretical tool or model for improvement. This will then set the criteria for a test to see if the theoretical tool with this therapeutic suggestion works.
Various suggestions for debiasing and limitations

In Chapter 4, we noted that studies in probability judgement are applicable to the case of judgement in design performance under uncertainty in the pre-parametric and qualitative condition. In the same sense, risky choices such as judging whether to choose this roof of certain form, are made without advance knowledge of the outcome or complete information or the aid of instruments, calculations or other normative prediction apparatus. The choice may be construed as a 'gamble', a ‘risk belief’ of the probability or likelihood of the roof performing. In this sense then all literature and studies on probability related to risk, overconfidence, and biases are applicable by analogy for our discussion in the context of design judgement and choice or decision-making. Suggestions for debiasing of judgement and choice, in the clinical, legal, political, economics, sociological or psychological, etc contexts, so that judgement and decision-making will improve and be closer to the normative rules of probability estimation can also be used for discussion in the case of design thinking in tropical architecture.

Brief survey of strategies for debiasing

Arkes (1986, 587) has written, “One technique that has proven to be absolutely worthless is telling people what a particular bias is and then telling them not to be influenced by it”. This is because the subjects do not actually know how to overcome these biases even if they know they may exist and affect them.
# Figure 7.1
Debiasing methods according to underlying assumption
(after Fischhoff 1982)

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faulty tasks</td>
<td>Raise stakes</td>
</tr>
<tr>
<td>Unfair tasks</td>
<td>Clarify instructions/stimuli</td>
</tr>
<tr>
<td></td>
<td>Discourage second-guessing</td>
</tr>
<tr>
<td></td>
<td>Use better response modes</td>
</tr>
<tr>
<td></td>
<td>Ask fewer questions</td>
</tr>
<tr>
<td>Misunderstood tasks</td>
<td>Demonstrate alternative goal</td>
</tr>
<tr>
<td></td>
<td>Demonstrate semantic disagreement</td>
</tr>
<tr>
<td></td>
<td>Demonstrate impossibility of task</td>
</tr>
<tr>
<td></td>
<td>Demonstrate overlooked distinction</td>
</tr>
<tr>
<td>Faulty judges</td>
<td>Warn of problem</td>
</tr>
<tr>
<td>Perfectible individuals</td>
<td>Describe problem</td>
</tr>
<tr>
<td></td>
<td>Provide personalized feedback</td>
</tr>
<tr>
<td></td>
<td>Train extensively</td>
</tr>
<tr>
<td>Incorrigible individuals</td>
<td>Replace them</td>
</tr>
<tr>
<td></td>
<td>Recalibrate their responses</td>
</tr>
<tr>
<td></td>
<td>Plan on error</td>
</tr>
<tr>
<td>Mismatch between judges and task</td>
<td>Make knowledge explicit</td>
</tr>
<tr>
<td>Restructuring</td>
<td>Search for discrepant information</td>
</tr>
<tr>
<td></td>
<td>Decompose problem</td>
</tr>
<tr>
<td></td>
<td>Consider alternative situations</td>
</tr>
<tr>
<td></td>
<td>Offer alternative formulations</td>
</tr>
<tr>
<td>Education</td>
<td>Rely on substantive experts</td>
</tr>
<tr>
<td></td>
<td>Educate from childhood</td>
</tr>
</tbody>
</table>
Fischhoff (1982, 422-444) has written an interesting review of debiasing (or de-biasing) suggestions from various studies for the context of overconfidence and the hindsight biases.\textsuperscript{1} In the table below taken from Fischhoff (op. cit.), one can see a list of debiasing strategies to improve judgement and decision-making.

Fischhoff's table is quite comprehensive but not exhaustive. It is indeed very interesting to note that there is a whole array of problem of judgement and suggestions for improvement. However, Fischhoff's conclusion is discouraging. He observed that on the whole the strategies do very little to correct the two biases he examined, compared to the effort and intensity they have been tried in various experimental studies.

**Evaluation of some strategies of debiasing**

Two most effective strategies from the study by Fischhoff above are: to make the task easier (or enhance the substantive abilities and available information the judge brings to the task), and to teach probability estimation skills (Fischhoff 1982).

**Making the task easier**

It is desirable to make the task easier for the architect where possible. It is however easier for the researcher to make the task easier for the judge in an experiment, but it is another thing to make the task easier for the architect. Perhaps his task can be made easier indirectly if he can be better trained and have more available information that help his pre-parametric and qualitative

\textsuperscript{1} Hindsight biases refer to exaggerations in people of what could have been anticipated in foresight, after the event happened. For more thorough discussion on this and debiasing, refer to Fischhoff 1982, 422-444.
design process, in his busy schedule of practice and design. His chances of making mistakes will be less.

**Teach probability estimation skills**

Various literature has discussed the problems in probability estimation and that it will help to teach probability estimation skills to experts making heuristic judgements (e.g. Fong and Nisbett 1991; Nisbett and Ross 1980; Kahneman and Tversky 1982b). Kahneman and Tversky (1982a, 1982b) provided ample evidence that base rates were grossly under-utilised in many instances of assessing probabilities. If the judge pays more attention to the base rates, prior odds, sample size, or think Bayesian; there will be immense improvements. Take the example of Steve (discussed earlier in Chapter 4), if available statistics shows that there were more farmers in the town (prior odds), the judge will be more accurate in his consideration that Steve could be a farmer rather than a librarian. However, there are no statistics for heuristic predictions of performances of climatic designs, and it is difficult to generate that in the real world for the architects. Certainly training the architects in statistical skills when these statistics are available may help.

**Considering alternative instances in hindsight bias**

Arkes (1986, 587) observed that the strategy of considering alternative scenarios reduces hindsight *bias*\(^2\), which is not directly applicable to our case. However, the idea of considering alternatives in design is not new. Architects do consider various options and alternative schemes before deciding a certain plan in his work. Time limitation to generate many alternatives for all aspects of design is also a great constraint. In fact, it is the

\(^{2}\) These are biases related to past events (e.g. Aschraft 1998, Kahneman and Tversky 1982) that are not applicable to this study, since our study is about future outcomes.
very reason why the architect employs the ‘dirty-rule’ of heuristics to make quick decisions in his work.

Strategies that are not feasible outside the laboratory setting

Arkes (1986, 587) also commented that some techniques are only suitable in the experiment but not possibly implemented in the real world. He cited the example of Chapman and Chapman (1967), where the strategy was to create negative correlations to correct the problem of positive correlations, and noted that it is not possible to rearrange correlations in the real world to promote the debiasing of diagnosticians.³

Decrease reliance on memory

Arkes (1986, 591) also proposed that the human judge decrease reliance on memory when making judgement and decision. In a diagnostic example, without access to a list of clinical symptoms that actually did or did not occur, one tends to remember the facts supportive of the hypothesis under consideration, and to forget the facts inconsistent with the hypothesis. The overconfidence due to bias from this availability could be avoided if one refers to the actual record, rather than working from memory. This is certainly true as our working memory, long-term memory and attention is limited. It will help the architects to do more sketches and refer to books and pictures rather than simply use the memory to solve his design. However, in the case project, the architect already worked from large detailed sketches, and not just from memory. The architect does recall precedents from mental memory and not always refer to books (any external medium) that help him remember. By comparing his design with a picture of the precedent may help sharpen judgement.

³ Please refer to Arkes (1986) and Chapman and Chapman (1967) for more information.
Train judges to reduce irrelevant information

Gaeth and Shanteau (1986, 450) developed a procedure to improve the training of soil test experts to evaluate soil without the aid of instruments or chemical process, as the laboratory test procedures will take several months. The training was set up in such a way as to test if accuracy of judgement by these experts will improve if the influence of irrelevant information were reduced. They have found that one reasonable approach to improving judgemental skill would be to train judges to reduce the use of irrelevant information.

This is quite interesting because architects as seen in Chapter 2 are saddled with multiple goals and attention grabbing considerations, be it aesthetic, social-cultural needs and operations, building construction, technology, cost and timing, etc. In the judgement of climatic performance, it might help to reduce the influence of irrelevant information momentarily for that specific judgement. But it will be difficult because the architect takes pride and strives on multiple synthesis and insight in design creativity, and may not know at any one time for sure which information is irrelevant.

A strategy by drawing attention to possible negative outcomes

Hoch (1984, 649), in Availability and inference in predictive judgement, showed with experiments that generating favourable outcomes first tends to blind people to possible negative outcomes. It makes them more confident that a favourable outcome will actually happen, owing to the availability bias of imaginability (or ease of imagining). On the other hand if people generate reasons for why certain outcomes will not happen, they are less ‘certain’ of the favourable outcome, or tend to be a lot more conservative or under-confident with their prediction.
In *Counterfactual reasoning and accuracy in predicting personal events*, Hoch (1985, 719, 729) argues for an intervention with an instruction to subjects to think why opposite outcomes may arise, so as to improve accuracy in self-prediction for future job search by graduating business students. Hoch showed that on average, the introduction of ‘con reasons’ improved the accuracy of predictions in his study by reducing overconfidence in judgements. According to him, “Potentially confirming information is more readily available than disconfirming information; subjects presuppose (and hope) that they are correct and then proceed to recruit evidence to support that conjecture without considering the other side”. If they were prompted to consider reasons why the opposite outcome may arise, they could be more accurate. In an analogue sense, creative architects tend to be optimistic and with positive mindsets towards what they are creating, and therefore can be subject to overconfidence in judgement. We may be able to debias and sharpen their judgement by asking them to consider negative or opposite outcomes. The strategy by Hoch above was applied in the social-economic context. However, we can consider the possibility of a similar strategy in the domain of architectural design.

We will discuss this in the framework of the *Kernel of Conceptual System* and *Performance-Operation-Morphology Framework*. From the theoretical model in the previous chapter, we see that overconfidence occurred in the fact in the *Performance-Operation-Morphology Belief Structure*. The designer’s success-oriented mindset caused his mind to focus on and expect ‘positive’ performance and operations in the morphology (form) being designed, i.e., he was optimistic. This also applies to the observer/writer judging the building form on site. Both the designer and observer were overconfident of what the forms ‘could’ do. Would their judgement be different if they were told to look at the ‘exception’ or the ‘opposite’, i.e. what the forms ‘could not’ do? Could this be a possibility for debiasing?
Introducing a rebuttal mechanism for debiasing in design thinking

Positive mindset in design thinking

We look at things and problems based on the mindset. Designers are success-oriented in their mental attitude in designing, with a positive bend. On the climatic performance of the large roof overhang, a designer’s positive mindset causes him direct his attention on positive outcome. In the example in the case study of a specific building project, the architect’s positive mindset causes him to focus on the positive operation or performance that match (representative of positive evidence) the precedent example. There is no expectation for the negative outcome.4

Similarly in the example of the observer (architect/writer) of the landscape street between buildings, his success-oriented mindset is reinforced by the salience of the fame and success of the architect and the precedent to focus on the positive outcome of the design (availability of positive evidence), and he judged the operation and performance of the form based on this attention and expectation.

Analogical to the example by Hoch (1985) discussed above, if we can change the mental focus by introducing a negative or opposite orientation of thinking of why the design might not work.

A theoretical model for argumentation supporting claims proposed by Toulmin (et al. 1984, 98), has a similar structure as the Morphology-

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4 In a design problem for sun shading for instance, there are both positive and negative aspects to analyse and solve. In a sense, the designer framed a partial set of the problem based on expectancy and attended to it habitually. “Framing is controlled by the manner in which the choice problem is presented as well as by norms, habits, and expectancies of the decision maker” (Tversky and Kahneman 1988, 172). He could work on analysing and judging the part that was shaded from solar radiation positively, or he could analyse the part that was not shaded at all in his design process, to be more comprehensive. Similarly you can judge a cup as half-full or half-empty with differing illusive meaning.
Operation-Performance Belief Structure we discussed, and has a rebuttal component or a mechanism for thinking about an exception that will disqualify presumptions in descriptive statements, claims or facts (we will refer to this as the Argumentation Model in this study). This Argumentation Model (Figure 7-2) is therefore suitable for our study, and we will discuss how the rebuttal component can be incorporated in our Kernel of Conceptual System for design thinking to deal with the problem of biases.

Figure 7-2
An Argumentation Model, after Toulmin (et al. 1984)

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5 The structure of the descriptive branch of the Kernel of Conceptual System (Tzonis et al. 1975) is similar to the argumentation model of Toulmin (et al. 1984) without the rebuttal mechanism.
Given our general experience in the field concerned,

In accordance with the resulting rules or principles,⁹

Claim
‘Climatic performance will be – Pf’

the claim.

Back
‘Large roof overhangs have been observed to provide shielding from sun and rain, and provide climatic comfort’

Warrant
‘Large roof overhang provide climatic comfort’

Qualifier
‘so, presumably’

Ground
‘Large roof overhang is of morphology – Mf’

These grounds support,

Rebuttal
‘Unless operation (Of) is not totally correct: unless the roof does not shade the sun or rain for certain time or weather’

⁹ Rules and principles overlap with analogical reasoning by examples in precedents, as discussed earlier in Chapter 2.
A descriptive thinking model with a rebuttal mechanism

To illustrate how the Argumentation Model (Figure 7-2) has a structure of interrelated components that are similar to the Morphology-Operation-Performance Belief Structure, we will use our case study as an example in the model (Figure 7-3).

The statement “These grounds support, in a qualified way, the claim”, where the ground is ‘large roof overhang is of a certain morphology (Mf)’, the qualifier is supported by the backing and warrant, and the claim is ‘a certain climatic performance (Pf)’, is similar to the fact “IF morphology (Mf), THEN performance (Pf)” in Figure 6-6 and Figure 6-8 in Chapter 6.

In the Argumentation Model, however is an additional component, the component of rebuttal. This rebuttal or disqualification is a mechanism to think about an exception (Toulmin et al. 1984, 97-99), for instance a reason why the operation (Of) is not totally correct: ‘Unless the roof does not shade the sun or rain for certain time or weather’. This is analogous to Hoch’s (1985, 719) proposal of thinking about the opposite outcome. In this way, the claim or the fact (IF-THEN) (descriptive statement) will be checked with an opposite orientation, and analogous to Hoch’s example, debias the illusions in the design thinking process.

Kernel of Conceptual System with a Rebuttal mechanism for debiasing

We will now incorporate the rebuttal component into the descriptive branch of the Kernel of Conceptual System we discussed in Chapter 6. This will complete the cognitive theoretical model or tool for understanding the problem of heuristics and biases in tropical architecture, and for therapy with
a rebuttal thinking mechanism (Figure 7-4). The rebuttal branch interacts with the fact to disqualify the belief with an exception.\(^7\)

This model will have to be tested with an experiment to see if it works for debiasing judgements of tropical design.

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**Figure 7-4**

**Kernel of Conceptual System with a Rebuttal mechanism for debiasing in design thinking**

(Modified from the Kernel of Conceptual System after Tzonis et al. 1978)

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**Criteria for testing the therapeutic model**

In his experiment, Hoch (1985, 729) put the remedial intervention before the first prediction under uncertainty. He noted: “An interesting test would be to have subjects first make predictions, next generate various reasons, and then reevaluate their initial judgements in light of the subsequently considered evidence. Given the usual strong desire to maintain cognitive consistency, the effectiveness of such a debiasing technique seems doubtful” (op. cit.). It would be interesting to test this out.

\(^7\) In a sense the rebuttal is part of the fact, or we can say it overlaps with the fact and challenges the fact or descriptive statement (belief).

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With the theoretical framework above, it is interesting to test whether the judge of adequacy of design in environmental control, when warn about possible bias, will actually shift his confidence level of a piece of architectural work he previously judged as high in adequacy. The test should incorporate examples where representativeness and availability, and the associated biases apply. The test should also check if he is shown and reminded of the possible opposite or negative outcome, for instance malfunctioning of the operation, whether he will make adjustment to his assessment of the adequacy in performance of the same morphology shown.

In this chapter we noted a few main points. Architectural publications and reviews are generally based on the positive success-oriented assessments of precedents, of what was attempted, accomplished and to analyse and state them as examples, types, rules and principles for future reference. Few are predicated on what could go wrong. Therefore, the architectural designer is generally trained and accustomed to a positive orientation, and develops a habit, pattern that constrains the mental focus and attention on what works. If the experiment to test this strategy show positive indications of improvement in judgement, then it is reasonable to discuss and study in future into how this can be introduced for use in practice and in the pedagogical system. The theoretical and therapeutic model we developed here will be useful in these applications. In the next chapter we will discuss a cognitive experiment used to check its reliability. The experimental set-up and procedures, results and analysis, and success of the several tests within the experiment will be presented and discussed.
CHAPTER 8

COGNITIVE EXPERIMENT

Testing of the therapeutic model for effectiveness in debiasing in design thinking

In the previous chapter, we proposed a therapeutic model with a rebuttal mechanism for debiasing in design thinking that is affected by biases, and the criteria for testing this tool. In this chapter, we will discuss the detailed framework and set-up of an experiment to test the effectiveness of a warning about bias due to representativeness and availability, and the effectiveness of introducing a rebuttal mechanism to each case. We will then discuss the results, the applications, and the limitations of this experiment.

Experiment set-ups and test results

Objectives of experiment

The experiment was designed to test the effectiveness of the following debiasing strategies, applied to test samples for judgements of designs for environment control:
i) Warning of representativeness bias.

ii) Warning of availability bias.

iii) Introduction of rebuttal mechanism.

These strategies were tested after subjects have made their initial judgements of various sample designs for environmental control. This is different from Hoch’s (1985) experiment where he argues that the strategy of making subjects think of arguments why their judgements may not be right is effective if introduced before the crystallization of feelings of uncertainty and judgement. He noted that, “An interesting test would be to have subjects first make predictions, next generate various reasons, and then re-evaluate their initial judgements in light of the subsequently considered evidence. Given the usual strong desire to maintain cognitive consistency, the effectiveness of such a debiasing technique seems doubtful”. One of the objectives (not the main goal) of the experiment in this study is also to test this interesting observation.

As discussed in the earlier chapters, the properties of similarity or representativeness or degree of match in precedents are used in preparametric and qualitative judgement of design. According to Tversky and Kahneman (1982a) and Osherson (1995) the extent of overconfidence in heuristic prediction/diagnosis or judgement of an instance corresponds to the degree of match or representativeness or similarity of the description of the item being judged to the characteristic of existing examples or beliefs or stereotypes. The representativeness biases are most suspected to operate in the judgement of designs where their visual image match or is representative of design of high performance, when in fact they do not physically perform to that extent in reality. The samples for testing representativeness biases were chosen based on the fact that they appear visually to offer much protection against solar radiation and rain, but they are lacking in actual performance by comparison to other samples.
Also discussed in earlier chapters, according to Tversky and Kahneman, (1982a) the extent of overconfidence in judgement of an instance corresponds to the *availability* or ease of retrievability from memory and *imaginability* in the mind. Samples used for testing *availability biases* were therefore chosen based on their fame and success both in the architects behind the building projects, and the fact that they were well published in recent international books and magazines. In the judgement of performances of these samples visually and mentally, the presence of *availability biases* is most suspected, compared to the less current and published samples.

**Test set-ups and procedure for testing biases and debiasing strategies**

**Overview of experiment**

Prior to a lecture, design student subjects were asked to judge the adequacy of sample designs for protection from solar radiation and rain to provide comfort and convenience in corridors or balconies, which are semi-enclosed user spaces. For simplicity and control of the experiment subjects are only tested on the judgement of effectiveness of design for the protection from these two environmental factors.

These judgements were made with the eyes and mind while viewing graphical representations of the designs, without aid of any measuring instrument, normative computation or simulation device. They were asked to make the first set of judgements without any prompt or interference so that it is similar to everyday design judgement with the eyes and mind. Next they judged each sample after being warned of existence of *representativeness* and *availability biases* corresponding with the relevant set of samples. And

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1 In actual practice, the designer has to judge the operation and performance of a lot more environmental factors including ventilation, humidity, glare, re-radiation, convection, etc.
finally judged after they were prompted to think with a different mindset or pay attention to why each design may not work.

Motivated student designers employed as subjects in the experiment

The subjects comprised 47 architecture Masters students who have been involved in architectural design, in design studios in school or in practice, for the tropical region for more than 4 years. All of them have completed their required practical training work in the architect’s office for at least 10 months. They were reasonably engaged in the complexity as well as rapid and heuristic process of architectural design, including the context of design for environmental control in Singapore. All the students were motivated to judge as best they could because they could find out how good their judgements were as part of their personal design and professional development. They were indeed very cooperative in submitting every questionnaire complete.

Parts of building projects in tropical Singapore used as test materials

The subjects were seated in a lecture hall where they were able to view the projected photographic slides of 8 samples of designs for corridors or balconies in Singapore (please see Appendix E, Figure E-1 for the samples), while they record their ratings in the answer sheets. These graphical representations were taken from completed buildings ranging from the traditional, the mid 1980’s and the contemporary famous projects. The subjects were shown each slide of the sample at a time (1 minute each) and asked to indicate on a scale of 1 to 10 their assessment (rating) of the adequacy of environmental control with the design in each façade in terms of
the protection from solar radiation and rain; i.e. to indicate a rating of 1 point for the least adequate and 10 for the most adequate.

Subjects were told that there were several parts to the experiment that will last half an hour, but were not told anything else until the revealing of necessary instructions for each part of the experiment. The 3 parts, Test 1 - Control Test, Test 2 - Warning Test, and Test 3 - Rebuttal Test were carried out sequentially with a short interval of about 5 minutes rest, while each set of test answer sheets was collected and subsequent set issued.

Test 1 - Control test and procedure

In the Control Test, a set of adequacy ranking of the sample designs was obtained. These Control Test data served as the values for comparison with Test 2 and Test 3 to see if there were any change in judgement as a result of interventions. The samples were shown to test subjects without any comments about the samples, except the name of the building projects they were taken from. They were not shown in any particular order of ranking, but the colonial house and the shophouse samples were shown first so as to form the initiating cue for calibration of high performance for the subject, where the traditional-time-tested projects were universally recognised as high in performance. The ratings of these cues were left to the subjects to determine by judging from the representation as well as their memory. The samples of designs of various balconies or corridors were taken from a typical colonial house, a typical shophouse, the Balestier Institute of Technical Education (Balestier ITE), Westlake Secondary School (Westlake SS), Ayer Rajah Community and Service Centre (Ayer Rajah CSC), Temasek Polytechnic, Bishan Institute of Technical Education (Bishan ITE), and Catholic Junior College (Catholic JC) (please see Appendix E, Figure E-

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2 It is assumed that no test for biases and debiasing in these time-tested examples is required.
1 for the illustrations). To simplify the judging process, all facades were assumed to be facing the East. 3

In this experiment, the samples of the colonial house, the shophouse, Catholic JC and Westlake SS were chosen because of their relatively high performance in the protection from solar radiation and rain offered by their design. Their relative performance were predetermined and verified with normative analysis 4 and ranked against the other four samples where biases were suspected.

The Balestier ITE and Ayer Rajah CSC samples were chosen because they appear visually to offer protection against solar radiation and rain, but their diagnosed performance by normative analysis are not as high as the colonial house, shophouse, Catholic JC and Westlake SS samples. According to Tversky and Kahneman (1982a), and Osherson (1995) heuristic predictive overconfidence of an instance corresponds to the degree of match or representativeness or similarity of the description of the item being judged to the characteristic of existing examples or beliefs or stereotypes. The representativeness biases are most suspected in these two samples based on the fact that their visual image match or is representative of design of high performance.

According to Tversky and Kahneman, (1982a) the extent of overconfidence in judgement or prediction/diagnosis of an instance corresponds to the availability or ease of retrievability from memory and imaginability in the mind. Availability is increased with salience, fame, and success, and the tendency of availability bias leading to error increases with the presence these characteristics relating to the instance being judged. Temasek Polytechnic and Bishan Institute of Technical Education samples are chosen because of their fame both in the architects behind the projects,

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3 The real facades of the Catholic JC and Westlake SS samples faced the North, which means that they are even more effective in performance. For this experiment, the normative are computed based on the East orientation, which will be lower, but comparable for comparison to the rest of the samples.

4 Calculations were made with the SOL-ARIS software (Lam and Mahdavi 2000), which was based on measured data of the solar radiation in the Singapore environment for the whole year. This system was a further development from an earlier version (Mahdavi and Lam 1994).
and the fact that they are well published in recent international books and magazines. The presence of availability biases is most suspected, compared to the less current and published Catholic JC or Westlake SS samples.

Test 2 - Warning test and procedure

There are two parts to the Warning Test, the warning of biases from use of representativeness and the biases from the use of availability. After the control test questionnaires were completed and collected, the subjects were warned of possible illusions of validity in representativeness that produced overconfidence in judgement. After the warning by explaining to the subjects that there could be biases due to similarity, the subjects were then shown slides of the samples of Balestier ITE, Westlake SS, and Ayer Rajah CSC, one at a time, and asked to judge or rate.

Next the subjects were warned of the biases of imaginability, triggered by popularity and fame, in availability that could create over confidence in judgement. After the warning by explaining to the subjects that there could be biases due to availability, the subjects were then shown slides of the samples of Temasek Polytechnic, Bishan ITE, and Catholic JC, one at a time and asked to judge or rate.

Test 3 - Rebuttal test and procedure

In the tests with the introduction with a rebuttal mechanism, the subjects were given an explanation that when we judge environmental design, we could check for the positive and the opposite outcome of the design operation and performance, and are asked to pay attention to arguments why the design may not work. This is done by showing an example of the visual-mental evaluation of a building façade (please see Appendix E, Figure E-2 for the illustration) with checks for both the positive and opposite outcome
for operation and performance. They were then shown the samples to rate in the same order as in Test 1, without any comments.

**Collation and processing of outcome data**

The experimental data were tabulated and checked for statistical means and confidence levels of differences (please see Appendix E, Figures E-3 to E-10 for the data) based on statistical guidelines for experiments and standard statistical analysis (Wickens 1998). A statistical t-test was conducted for each change in the mean ratings, so as to establish the confidence level (of 95% and 90%) that each change was true positive or significant.\(^5\) If it was significant, it means that it is valid to say that the intervention resulted in a positive change in judgement.

**Summary of results of tests for biases and debiasing**

The experiment showed the adjustments to judgements in response to warning of both biases due to *representativeness* and *availability* was slight. The introduction of rebuttal mechanism, however, resulted in marked adjustments in the judgements of those samples where *representativeness* and *availability biases* were detected.

\(^5\) We noted that there might be a difference with the use of the Mann-Whitney test (Blalock 1979, 265) instead of the t-test to verify the significance of the changes in mean rating of 1 to 10, from control-test to warning-test, and control-test to rebuttal-test. We assume the difference may not affect much.
Figure 8-1
Comparative ranking of effectiveness of solar radiation and rain protection of test samples between actual calculated effectiveness and experimental judgements

<table>
<thead>
<tr>
<th>Samples</th>
<th>Rank-ing</th>
<th>CALCULATED EFFECTIVENESS (Unknown to experimental subjects)</th>
<th>JUDGED EFFECTIVENESS (Mean ratings by subjects)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ineffective* protection</td>
<td>Solar radiation</td>
</tr>
<tr>
<td>Colonial house</td>
<td>1\textsuperscript{st}</td>
<td>13% to almost 0%***</td>
<td>30% to almost 0%***</td>
</tr>
<tr>
<td>Shophouse</td>
<td>2\textsuperscript{nd}</td>
<td>15% to almost 0%***</td>
<td>34% to almost 0%***</td>
</tr>
<tr>
<td>Catholic JC</td>
<td>3\textsuperscript{rd}</td>
<td>12%</td>
<td>25%</td>
</tr>
<tr>
<td>Westlake SS</td>
<td>4\textsuperscript{th}</td>
<td>14%</td>
<td>30%</td>
</tr>
<tr>
<td>Bishan ITE</td>
<td>5\textsuperscript{th}</td>
<td>18%</td>
<td>41%</td>
</tr>
<tr>
<td>Ayer Rajah CSC</td>
<td>6\textsuperscript{th}</td>
<td>26%</td>
<td>62%</td>
</tr>
<tr>
<td>Balestier ITE</td>
<td>7\textsuperscript{th}</td>
<td>38%</td>
<td>88%</td>
</tr>
<tr>
<td>Temasek Polytechnic</td>
<td>8\textsuperscript{th}</td>
<td>46%</td>
<td>99%</td>
</tr>
</tbody>
</table>
Cognitive Biases in Design

Notes:
* The lesser the ineffectiveness, the higher the effectiveness, i.e. 1°, the highest in effectiveness has the lowest ineffectiveness. Assume all facades face the East for this test.
** The openness of the balcony or corridor space to the scattered rain, which could come from many directions and angles because of wind, was assumed for ranking sake to be proportional to the openness to the sky or exposure to diffused lighting. For simplification of the experiment, the direct effects from being wet by rain and the heat impact from solar radiations are assumed of equal importance to the subjects.
*** For the colonial house and shophouse sample, the modulation of solar radiation and rain are flexible because of the provision of bamboo blinds or canvas. Therefore the ineffectiveness varies from, when blinds are up, to when they are down, and the permeability of solar radiation and rain through the blinds. Traditionally these designs are time tested and considered as some of the most effective for the tropical environment. The most effective of course is an opaque wall.

The ranking of actual computed effectiveness of sun shading and rain shielding are placed against the experimental judgements in the table below (Figure 8-1). The ineffectiveness figures\(^6\) are expressed as percentages, where 0% ineffectiveness means 100% effectiveness or complete protection (like the case of an opaque wall). The figures were derived from calculations of solar radiation shading for a vertical plain at the mid point of the balcony or corridors, for the average day in Singapore.\(^7\) The openness of the balcony or corridor space to the scattered rain, where rain could come from many directions and angles because of wind, is assumed for ranking sake to be proportional to the openness to the sky similar to the case for diffused solar radiation. (Please refer to Appendix E, Figure E-1 for more details of samples and values used for calculations).

\(^6\) It is interesting to note that percentages of effectiveness appear high because 50% of the time, a façade is not facing the sun in a day. Effectiveness of 80% is also 20% ineffective. In the same spirit as this study on bias, the negative, 'what can go wrong', figures are used for our analysis.
\(^7\) Calculations were made with the SOL-ARIS software (Lam and Mahdavi 2000), which was based on measured data of the solar radiation in the Singapore environment for the whole year.
Analysing for biases and effectiveness of debiasing strategies

In the control test, the colonial house and shophouse samples that have the highest time-tested performances were experimentally rated as 7.5 and 6.7 respectively (Figure 8-1). Relative to the calculated effectiveness ranking and experimental rating of the colonial house, shophouse and Catholic JC samples, the relative experimental rating and ranking position of the judgement of Catholic JC is reasonable. Looking at the calculated effectiveness, the Bishan ITE corridor design was experimentally rated relatively much higher than warranted, mean of 6.6 compared to 6.0 for the Catholic JC sample, which has higher calculated performance than the Bishan ITE sample\(^8\). The experimental rating for the Westlake SS sample appears slightly high compared to the Catholic JC sample, but statistically, the ratings are too close for us to be conclusive.\(^9\) Therefore the experimental rating and ranking for the Westlake SS sample is close to that for the Catholic JC sample, and appears reasonable, compared with the calculated effectiveness ranking position. By similar relative comparison of calculated effectiveness to the Catholic JC sample, the experimental ratings for corridor designs of the Ayer Rajah CSC, Balestier ITE and Temasek Polytechnic, are also on the high side.

For the discussion below, the analysis for the presence of biases, and the effectiveness of the warning strategy and rebuttal strategy are grouped under each of the biases.

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\(^8\) Note that the ratings and rankings are relative to this particular set of samples and normative performances, and not absolute. It would be interesting to develop a system of ranking tropical architecture relative to a very large set of empirical examples as a calibration to train judgement for design choices.

\(^9\) The variance in experimental ratings for the two samples are too close, 6.0 to 6.3 and 6.1 to 6.2 respectively.
Testing representativeness biases and debiasing strategies

The tests with the Ayer Rajah CSC sample showed 95% confidence that there were true positive reductions in the experimental effectiveness ratings from the control mean of 5.5 to adjusted mean of 4.9 (-10%, slight change) after the warning of representativeness bias, and to 4.2 (-23%, marked change) after the rebuttal intervention. Compared to the calculated effectiveness and ranking of the Catholic JC sample (Figure 6-1), the rating mean of 4.2 appears a lot more realistic than the initial 5.5 which is too close to a mean rating of 6.0 for the Catholic JC sample.10

The test for the Balestier ITE sample showed 90% to 95% confidence that there were true positive reductions in the experimental ratings from control mean of 5.4 to adjusted mean of 4.8 (-11%, slight change) after the warning of bias, and to 3.9 (-28%, marked change). This is more realistic compared with the Catholic JC sample ranking and rating, where 3.9 is much further from 6.0 than the initial 5.4 estimation (Figure 8-1).

There was no significant change of the experimental rating in the Westlake SS sample, as anticipated in the test set-up. Could it be that there was the bias of representativeness but the interventions did not work? This is unlikely the case, because the experimental ratings of the other two samples above indicated the presence of representativeness biases as anticipated, and that where there were representativeness biases they were shown to be adjusted through the interventions of warning (very slight) and rebuttal (marked change). So it is more conclusive in this experiment that there was no bias of representativeness in the case of judgements for the Westlake SS sample.

The experiment has shown true positive results in improvements to judgement and debiasing representativeness bias through warning of bias

10 Ibid.
with slight improvement, and introduction of rebuttal with marked improvement.

Testing availability biases and debiasing strategies

Both Bishan ITE (by Akitek Tenggara) and Temasek Polytechnic (by James Sterling and Michael Wilford) are famous, current and well-published projects designed by famous architects. The effects of availability biases in judgement are more suspected because of these property of salience that increase ease of retrievability from memory and imaginability in mind of the success of the projects. Catholic JC is not a well-featured project and it was completed in 1977, though the architect Alfred Wong is an important architect in Singapore.

The test for the Bishan ITE sample showed 95% confidence that there were true positive reductions in experimental ratings from control mean of 6.6 to adjusted mean of 5.9 (-10% slight change) after the warning about possible availability bias, and to 5.6 (-17%, marked change) after the introduction of rebuttal mechanism.

The test with the Temasek Polytechnic sample showed no significant change of experimental effectiveness rating from control mean 4.8 to 4.7 after warning of availability bias. There was however a significant change in mean to 4.1 (-14%) of 95% confidence after the introduction of a rebuttal mechanism. This could be that the building and architect were so famous that being warned of the bias did not make a difference and was not effective at all to debias, but there was a difference only if there was a change of mind set through the introduction of a rebuttal mechanism, to challenge them to think of opposite outcomes. From the normative calculation, the first storey space of the corridor is very poorly shaded, almost zero for half the day (49% ineffective shading of direct solar radiation means almost zero shading for half a day when the sun is in the East, i.e. zero effectiveness for the overhangs or lattice device).
As anticipated in the test set-up, there was no significant change to judgements for the Catholic JC sample, from control mean of 6.0 to 5.9 after the warning of bias, and to 6.3 after the rebuttal intervention. Similar to the case for Westlake SS sample above, this was probably because the judgements were unaffected by the bias in availability in the first place.

The experiment has shown true positive results in improvements to judgements and debiasing availability bias through the introduction of rebuttal mechanism, with mark improvements. There were true positive results in improvements to judgements and debiasing of availability bias through the warning of the bias, with very slight improvement for one test sample. There was no effect for the other sample where the bias was present, which could only be debiased by introducing the rebuttal.

**Overall conclusion of the experiment**

The experiment showed that the warning about the existence of both representativeness and availability biases only helped slightly or was of no help in improving heuristic judgement. The experiment however shows that the introduction of a rebuttal mechanism in design thinking was effective in debiasing, and contributed much improvement in design judgement, in the case of tropical architecture.

**Limitations of the experiment**

The analyses of the improvements in accuracy here are based on relative ranking and proportioning of experimental ratings and calculated effectiveness for sun shading and rain protection. The experimental rating scale of 1 to 10 are ordinal scales, and do not necessarily correspond directly with the normative scales of percentages of calculated effectiveness, but are
relative scales limited to the set of samples. There is no existing training for the architect to look at a building design and gauge (without calculation or computer simulation) the percentage effectiveness of sun shading that correspond to the normative scale. If there is this training, then each experimental rating can be directly compared with the normative calculated rating to know if the architect is accurate in his judgement.

It will be interesting to collect enough examples of actual building designs with their empirical and holistic operations and performances in climatic modulation to develop an appreciation of the level of effectiveness and ineffectiveness, and a rating scale for all these precedents, and allow designers to learn this scale so that they can make heuristic ratings that are directly corresponding to calculated ratings that they learnt. These can be used in education and in practice to help build up more helpful precedents with varying scale of effectiveness for future judgement. This is quite in line with Hawke’s (1996, 51) suggestion of building up a collection of precedent cases of actual buildings in operation as ‘complete environmental systems’, with both the quantitative and pre-parametric descriptions, for guiding future design thinking, and avoiding the stereotype effects of highly deterministic typologies (discussed in Chapter 2).
The experiment shows that warning of both biases due to representativeness and availability only helped improve judgements slightly or had no significant effect. The introduction of a rebuttal mechanism to think of the opposite outcome, however, resulted in effective debiasing for both biases present, and resulted in marked improvements in accuracy for heuristic judgement in design thinking, in the case of tropical architecture.

From this experiment in this chapter, and the understanding of how biases affect judgement and decision in the previous chapters, it will be very important to emphasise the use of rebuttals in education and in practice. The habit of architectural education and practice is to look at the positive performance of design. It is important to change this mindset for better accuracy in design, since designs rely heavily on heuristics in practice.

In the next chapter (concluding chapter) we will summarise the main findings of this research, and discuss the general applicability of the theoretical model developed here, the limitations and improvements, and possible future extensions of the research and applications of the knowledge.
CHAPTER 9

EVALUATION AND CONCLUSION

*Summary of the findings, contributions, limitations, and potential extension and generalisation of thesis*

In this concluding chapter we will summarize the major ideas, contributions and limitations of the thesis. We will discuss also the potential extension, generalisation, limitations, and application of the present work in the last section.

**Summary of major ideas in this study**

**Errors in design judgements and decisions are linked to biases, in the case of tropical architecture**

We pointed out in the introduction that we seek to investigate,

i) How cognitive *biases* (or illusions) may lead to errors in design thinking,
ii) Why architects use architectural precedents as heuristics despite such possible errors, and

iii) Develops a design tool that can overcome this type of errors through the introduction of a rebuttal mechanism. The mechanism controls biases and improves accuracy in architectural thinking.

We used an interdisciplinary research method, drawing on knowledge from cognitive science, environmental engineering, and architectural theory. We also used the case study approach. The case of tropical architecture in Singapore was used for the investigation. We drew on the work of Tversky and Kahneman on heuristics and biases to understand the problem design errors in the case study of a specific building project (Chapter 5). Two examples of design-thinking structures with errors were modelled with the Kernel of Conceptual System and the Performance-Operation-Morphology Framework of Architectural Knowledge (Chapter 6) to understand the problem in detail. We discussed several debiasing strategies, and proposed one possible strategy for controlling errors by introducing a rebuttal mechanism. This was applied to the model (Chapter 7) and tested with an experiment (Chapter 8). The following are the main findings:

1. The architect has to deal with multiple criteria in designing. Incomplete information, limited time, and human mental resources make design thinking in practice difficult and impossible to solve. It is not possible to analyse all possible alternative solutions, multiple contingencies and multiple conflicting demands, as doing so will lead to combinatorial explosion (Chapters 1 and 2).

2. One of the ways to cope with the difficult design problem is to use precedents as heuristic devices, as shortcuts in design thinking. Precedents are embodied in examples, types, rules, and principles. And they are used with analogical, pre-parametric, and qualitative means of thinking, without quantitative calculations (Chapter 2).
3. Heuristics have associated cognitive biases (or illusions) that lead to errors. The use of representativeness (based on similarity) and availability (based on ease of recall and imaginability) for design thinking can result in cognitive biases of illusions of validity and biases due to imaginability respectively. These can explain the errors in judgement and decision-making in tropical design for environmental control. These judgements include predictions of performance outcome of a new design, and the post-design evaluations of completed designs that become precedent knowledge for future design thinking (Chapter 4, 5, and 6).

4. Knowing that one is affected by cognitive biases does not help much to alleviate the problem of errors in design judgement. The experiment shows that the mindset of the success-oriented designer can be refocused with a rebuttal mechanism on the negative and opposite outcomes, in order to debias the illusions (Chapter 8).

We know that the therapeutic tool developed here works within the case of tropical architecture. What is its general applicability to the entire architecture domain, and the wider context of design in other domains? We will discuss these and the limitations in the following section.
Extensions and generalisations

General applicability to the architectural design domain, other design domains, and limitations

Can this understanding and therapy be generalised to all architectural design problems? What elements and structure are common to other areas of architectural design so that the arguments can also apply there? We know that all architectural design has the elements and structure of performance-operation-morphology, even though the context changes. As long as we are designing for human beings, the requirements of climatic comfort and convenience do not change. Building materials and method of construction are employed towards fabricating a desirable expression that also meets the required performance. These aspects and their relationship are clearly universal for all climates.

Can this be applicable to a sub-domain in architecture? Say the design of a doorknob? There will be a norm for the performance of a doorknob, its operation, and its form. There will also be the reference to precedent knowledge to guide the design of a new doorknob, requiring assumptions or beliefs, for heuristic design judgements and decisions. There will also be the possibility of biases and thus the applicability of the debiasing model. Since the design for a doorknob is not as complex a design problem as for a building façade, then there is the potential for generalising the understanding and tool to such design process to prevent errors from biases.

Can it be generalised to other design domains? The methodology and unravelling of the design process in this study is based on the case of tropical architectural design. There are possibilities of generalising the understanding of the problems derived from this study to other design domains with similar design processes employing heuristic methods. These design domains can include interior design and industrial design, where actual designs may fall
short of intentions or beliefs in expected performance. Let us take interior
design for instance. The problem is similar, the performance-operation-
morphology applies, and precedent knowledge can also be used to guide
design thinking. In this sense the model can also be applied to interior
design, and other industrial design of similar complexity, but of smaller
scale.

Generalisation to the domain of urban design will be more difficult.
Architectural design like urban design is multi-criteria.\textsuperscript{1} However, urban
design involves many disciplines and is relatively larger in scale than
architectural design.\textsuperscript{2} Perhaps, generalisation may be possible in a limited
sense to a small subset of urban design. For instance, generalisation may be
possible for the design for climatic environmental control in urban design
that overlaps with architecture.

**Applications, improvements, and future extensions of this research**

The therapeutic model was tested in a controlled environment of designer
subjects who were instructed to think of the opposite outcome before judging
again after an initial round of judgement. We know that the strategy of
debiasing showed positive effects in the controlled environment. In the real
life situation, the designer is independent without someone giving the
instruction. How can the strategy of debiasing be introduced?

Perhaps the answer lies in how one may educate designers with the
problem of biases and the strategy for debiasing so that he may remember to
self administer the instruction to think of the opposite (in this case negative)
outcome, when the usual design mind is optimistic and success-oriented.

\textsuperscript{1} Please refer to Tzonis and Salama (1975) on the multi-criteria aspects in architectural evaluation.

\textsuperscript{2} Please refer to Shefer and Kaess (1990) for more details on multi-criteria and multi-dimensional
aspects of evaluation of urban and regional planning.
In this study we also investigated the understanding about nature of the architectural thinking process. The following are suggestions for extensions to this research, if it can be extended:

i) Train subjects in the use of rebuttal mechanism, and see if they retain this lesson and are able to self-administer the strategy of debiasing.

ii) Study how quantitative design guidelines can be adapted in a way that is more accessible to architectural designers. Investigate whether they can be made more sympathetic and user-friendly to the creative process with analogical, pre-parametric, and qualitative means of design thinking.

iii) Increase in the pool of accurate reading materials reporting precedents without imbedded errors will possibly improve design. Study how the introduction of reading materials that highlight counterexamples (examples that show errors) will help sharpen design thinking in the design studio.

Applications for practice, pedagogy, and research

Applications in practice

At a time of great emphasis on sustainable designs and of debates on localisation through environmentally sensitive designs, this study will serve to help understand the problems related to the design process. Prior to this understanding, practitioners may be largely misunderstood for being insensitive and irresponsible. This being the chief causal explanation, the environmental advocates by and large rely on moral-persuasions, expending much effort and time moralising and explaining why one should be sensitive,
instead of helping the designer overcome the obstacles of cognitive biases in design.

**Application in education**

Knowing the problems of biases, and strategy for debiasing, means that the designer can be more conscious to minimise the pitfalls. Educators, writers and advocates of environmentally sensitive designs may know better how to prepare guiding principles for designers avoiding the potential of errors owing to biases. These modified guiding principles should include the rebuttal of why assumptions and judgements could be inaccurate. The usually optimistic mindset of the designer should be refocused on possible problems.

Students are trained to expand their imaginations for creative possibilities in the design process. Careful emphasis need also be given to include negative reasoning in the design training. Habits of design are developed through the years of design training, and one built with a rebuttal check in the design thinking process will go a long way, leading to real practice. Schon (1983, 49, 61) proposed a reflective practice for architectural work, where the architect practices design as a “reflection-in-action”, that he should “not miss important opportunities to think about what he is doing” in order to correct patterns of error in repetitive experience in practice. An emphasis on rebuttal arguments will sharpen the reflection in practice, and therefore sharpen output. Better comprehensive understanding of environmental parameters will also sharpen the design judgement, as well as ability to rebut incorrect assumptions.

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Indigenous traditional architectural design has always been designed intuitively and refined through feedback over long periods of trial and error into more stable typologies. In the modern context of rapid development with new and changing technologies, there is insufficient feedback information, and time to digest and respond to feedbacks. Dean Hawkes (1996) proposed the collection of precedent cases with both pre-parametric and parametric analysis of good buildings for guiding future designs. From this study, it is argued that not only the degree of successes should be recorded and reflected, but the shortfalls of each precedent should also be highlighted as counterexamples; the areas of success or failure in each building precedent should be differentiated.

Many published materials can carry reports of various buildings with wrong judgements about their design performance. If the designer uses these examples as precedents in new designs, then errors can arise. Writers need to know that they can be wrong, and that they need to be comprehensive in checking actual design performances before reporting them.

**Relation to other studies in theory of design thinking**

This thesis also covers a different angle and adds to the research works on design thinking and cognitive studies at the Design Knowledge Systems Research Centre at Delft University of Technology. In Nan Fang’s (1993) computational tool for architectural precedent analysis, precedents are taken for granted or assumed or believed implicitly to be suitable or right for the new design. We have shown however that these implicit beliefs in the precedent cases could be ‘faulty’ or inaccurate because of biases. These happened both in the learning process and the application process of precedents for guiding judgement and decision-making. The computational approach of using precedent analysis for design could be enhanced with a rebuttal mechanism for better accuracy and validity in judgement and decision-making.
In Hoang-Ell Jeng’s (1995) dialogical model for participatory design, the conflicts of various beliefs of participants in the community, in discussing design requirements and directions for new community building projects were made explicit so that a more accurate understanding of the problem and a better solution could be reach. The conflict-arguments of various minds in the participatory design process were made explicit for resolution and improvement of judgement and decision-making. In our discussions, we dealt with making explicit the negative arguments within the complex mind of the designer who has multiple considerations in the design process, so that he can sharpen his judgement and decision-making.

**Extension to research in cognitive science**

In the field of cognitive psychology, there is continuing research into the issue of judgement and decision by intuitions and the related illusions or *biases* for predictions in statistical, clinical, legal, political (e.g. Fischhoff 1982; Arkes and Hammond 1986; Edwards and von Winterfeldt 1986; Fong and Nisbett 1991; Nisbett 1993; Heath 1994; Evans 1995), scientific and educational (e.g. Donley and Ashcraft 1992; Hoch 1985; Gaeth and Shanteau 1986; Goldstein, and Hogarth 1997; Payne et al. 1997) domains. These studies build on the earlier researches in the 1960’s and 1970’s on the psychological illusions by P. C. Wason, P. N. Johnson-Laird, A. Tversky and D. Kahneman that affected judgement of the probabilities or likelihood of outcomes leading to errors in decision-making in professional practices other than architecture domain (e.g. Wason and Johnson-Laird 1968; Kahneman and Tversky 1982). In artificial intelligence that is closely related to cognitive psychological research, human heuristics are studied in relation to problem solving (e.g. Haugeland 1977; Tzonis and White 1994; Cross et al. 1996; Winston 1992). In this study, we added one new dimension of the study of heuristics and *biases* in the architectural design domain.
Conclusion

We applied an interdisciplinary research method that employs knowledge from cognitive science, environmental engineering, and architectural theory. The case study approach was also used.

We examined how the problems of inaccuracy in judgements and decisions in architectural design for the tropical climatic environment, even though the architect is most of the time rational in his daily activities, is linked with biases. We understand that designers resort to the use of precedents as heuristic shortcuts because it enables them to cope with the difficult design task in practice efficiently and with reasonable effectiveness, even at the risk of errors. We established that appropriate refocusing of the mind on opposite outcomes in judgement with a rebuttal mechanism could debias these biases, and thus improve design judgement.

The tool was developed in the case of tropical architecture, and the debiasing tests were done in the limitations of an experimental setting, not in real practice. There are possibilities of generalising the understanding to domains of similar design complexity and scale, including interior design and industrial design. There can be applications in design practice and education, and in particular, in the designing of sustainable environments. If it can be extended, these are probably a few promising areas to extend the research work we have begun.
SAMENVATTING

Nederlandse samenvatting van het proefschrift.¹

Dit proefschrift onderzocht:

i) Hoe cognitieve vooroordeLEN of illusies kunnen leiden tot fouten in het ontwerpen.

ii) Waarom architecten, ondanks dergelijke mogelijke fouten, architectonische precedenten als heuristiek gebruiken,

iii) En ontwikkelt een ontwerpmethode die dit soort fouten vermijdt door het introduceren van een mechanisme van argumentatie en weerwoord. Dit mechanisme kent geen vooroordeLEN en verbetert de nauwkeurigheid in het ontwerpen.

De toegepaste onderzoeksmethode is interdisciplinair. Het maakt gebruik van kennis op het gebied van de cognitieve wetenschap, milieutechniek en architectuurtheorie. Er is tevens gebruik gemaakt van de benadering vanuit de "case study". Dit onderzoek richt zich op de tropische architectuur.

Het onderzoek naar architectonische vooroordeLEN put uit werk van A. Tversky en D. Kahneman, 1982, over "Heuristiek en vooroordeLEN". Volgens Tversky en Kahneman kan het gebruik van de heuristiek met behulp van representativiteit (gebaseerd is op gelijkenis) en beschikbaarheid (gebaseerd op moeilijke herinnering en een vlot voorstellingsvermogen) voor beoordeling van waarschijnlijkheid, resulteren in respectievelijk cognitieve vooroordeLEN van geldigheidsillusies, en in vooroordeLEN als gevolg van voorstelbaarheid. Deze theorie kan analoog gebruikt worden om te begrijpen hoe fouten ontstaan in de
Cognitive Biases in Design

beoordeling van verscheidene ruimtelijke configuraties, met als gevolg ontwerpen die na realisatie niet naar behoren functioneren.

Onvolledige informatie, beperkte tijd en gebrekkige menselijke intelligentie maken het ontwerpdenken in de praktijk moeilijk oplosbaar. Het is onmogelijk om alle mogelijke alternatieven, de veelheid aan toevallige voorwaarden en de verschillende conflictierende vereisten te analyseren, omdat dit zal leiden tot een combinatorische explosie. Een manier om met het moeilijke ontwerpprobleem om te gaan, is het gebruik maken van precedenten als heuristische middelen als "shortcuts" in het ontwerpdenken, met echter een kans op fouten. Dit wordt gedaan met een analoge, pre-parametrische en kwalitatieve wijze van denken, zonder kwantitatieve berekeningen.

Heuristiek kan efficiënt zijn en redelijk effectief, maar is niet altijd goed genoeg of zelfs onjuist, omdat het met cognitieve vooroordelen geassocieerd kan worden. Er worden verschillende strategieën besproken die "van vooroordelen ontdoen" en één mogelijkheid is het introduceren van een mechanisme van argumentatie en weerdord om het denken van de ontwerper te richten op de negatieve en tegenovergestelde resultaten van zijn beoordeling, om de illusies van vooroordelen te ontdoen.

Het onderzoek is verricht in het kader van de ontwerptheorie ontwikkeld door the Design Knowledge System Research Centre, TU Delft.

Deze strategie is getest aan de hand van een experiment. De resultaten tonen aan dat het invoeren van een mechanisme van argumentatie en weerdord, ontwerpbeoordeling aanzienlijk verbetert en ontdoen van vooroordelen inzake milieucontrole. De ontwikkelde methode zou mogelijk kunnen worden toegepast in de ontwerppraktijk, onderwijs en vooral in het ontwerpen van een duurzame omgeving.

Kernwoorden:
Ontwerp vooroordeel
Ontwerp kennis
Ontwerp gebaseerd op argumentatie en weerdord
Ontwerp precedent
Pre-parametrisch ontwerp
Tropische architectuur
Duurzaamheid

¹ Vertaling Merel Miedema

182
APPENDIX A
Illustrations of tropical architecture

Illustrations of tropical architecture for Chapter 1

Figure A-1
Indigenous traditional house in Malaya with large roof overhangs, and porous facades for cross ventilation (Source: Edwards 1990)

Figure A-2
An example of a house in Singapore with the colonial influence, adapted for the regional climatic conditions. Sun Yat Sen Villa, 1880's (Source: Edward 1990)
Figure A-3
Typical shophouses in Singapore, with 'five-foot-ways' providing continuous shelter for pedestrians in the city
(Source: Author)

Figure A-4
Kallang Airport, Public Works Department (1937) with pronounced horizontal sun-shading fins (Source: Author)

Figure A-5
Asia Insurance Building, Ng Keng Siang (1954) with horizontal sun-shading fins giving the distinctive character to the high-rise office building (Source: Author)
Figure A-6
Singapore Conference Hall and Trade Union House, Malayan Architects Co-partnership (Source: Ministry of Culture and Social Affairs 1965)

Figure A-7
Malaysia Singapore Airways Building, Malayan Architects Co-partnership (1965) with patterned sun-shading devices (Source: E. J. Seow 1973)

Figure A-8
People’s Park Complex, Design Partnership (1970) with naturally ventilated apartments in a tower over the podium shopping centre with the ‘City Room’ concept (Source: DP Architects)
Figure A-9
Woh Hup Complex, Design Partnership (1973) with terraced apartments over shopping podium below, with urban streets through atrium space (Source: DP Architects)

Figure A-10
Portion of sketch proposal of an experimental urban model for the new tropical Asian City with various levels of sheltered connecting urban streets, based on the design of Woh Hup Complex, SPUR (1971) (Source: SPUR 1971)

Figure A-11
Institute of Technical Education at Bishan, Akitek Tenggara (1993) with the design language of 'line, edge and shade' (Source: Author)

Figure A-12
Reuter's House, William Lim Associates (1990) with the intention of evoking traditional form with modern construction and usage (Source: Bay et al. 1998)
Figure A-13
Tanjong Katong Secondary School, Public Works Department (1999), with large horizontal louvers that do not shade any windows, while the circulation stair core is glazed without protection from solar radiation (Source: Author)

Figure A-14
Institute of Technical Education at Balestier, Architect Vista (1997) with illusive façade of shading lattice and louvers, which do not work properly (Source: Author)

Figure A-15
House No. 5, Lorong 105, Changi Road (1997) with strange inconsistency of façade treatments for climatic control. Front façade faces West (Source: Author)
Figure A-16
Bedok Condominium, Associates Group Architects (1985), recreating traditional tropical community streets and semi-public spaces in the sky (Source: Author)

Figure A-17
The Market Place, TANGGUANBEE ARCHITECTS (1995), with new large roof overhang reminiscent of the markets of the past (Source: TANGGUANBEE ARCHITECTS)

Figure A-18
Institute of Southeast Asian Studies, Public Works Department (1997) with an interplay of modern and traditional forms (Source: Author)
APPENDIX B

Illustrations of bioclimatic design guidelines

Illustrations of bioclimatic design guidelines discussed in Chapter 2

All illustrations in the following pages are after Olgyay and Olgyay (1963) as discussed in Chapter 2.
Figure B-1
A diagram showing the relation of the human body to the climatic elements, mathematically represented by covariations of air temperature, radiation, air movement, and relative humidity that interact with the human body and metabolism to cause conditions of thermal comfort.
Figure B-2

An example of a bioclimatic chart showing a comfort zone experimentally determined by having human subjects indicate instances of feeling comfortable with varying environmental elements of air temperature, air movement, air pressure, and relative humidity. The chart is for the temperate (moderate) zone with adjustments for use in areas with other latitudes.

[Image of a bioclimatic chart]

45. Bioclimatic Chart, for U.S. moderate zone inhabitants.
Figure B-3
An example of air movement pattern diagrams as guidelines for design established with wind tunnel tests

Effect of overhang on air flow. Note that overhang collects air streams which otherwise would escape; thus enhances incoming flow effect.
**Figure B-4**

And example of graphical calculation charts for sun-shading designs

<table>
<thead>
<tr>
<th>Horizontal Types</th>
<th>Section</th>
<th>View</th>
<th>Example</th>
</tr>
</thead>
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<td>Horizontal types</td>
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<td>View</td>
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</table>

Examples of various types of shading devices.
Figure B-5
An example of graphical guidelines on basic form and building shapes in different climatic regions.
APPENDIX C

Illustrations of a specific building project

Illustrations of a specific building project discussed in Chapter 3

The followings are illustrations of the Bishan Institute of Technology (Bishan ITE), as discussed in the case study of a specific building project in Chapter 3.

Figure C-1
Bishan ITE East façade with large louvers (Source: Author)

Figure C-2
Bishan ITE amphitheatre with large roof above (Source: Author)
Figure C-3
Bishan ITE amphitheatre with large roof above (Source: Author)

Figure C-4
Bishan ITE amphitheatre with open sided large roof above (Source: Author)

Figure C-5
Bishan ITE landscaped street between 3 and 4-storey blocks with open sided corridors and staircases (Source: Author)
Figure C-6
Bishan ITE Site Plan (Source: Akitek Tenggara in Powell 1997)

Figure C-7
Bishan ITE First Storey Plan (Source: Akitek Tenggara in Powell 1997)
Figure C-8
Section across amphitheatre (Source: Akitek Tenggara in Powell 1997)

Figure C-9
Section across East and West block and landscaped street (Source: Akitek Tenggara in Powell 1997)
Figure C-10
An example of a traditional house in Malaya (Source: Edwards 1990) The indigenous traditional house was referred to as the precedent for the principle for climatic design used for the Bishan ITE project.

Figure C-11
House on Mt. Rosie, which was a 'source of for the language of Line, Shade and Edge' (Source: Tay Kheng Soon in Powell 1997)

Figure C-12
Boy Scouts Association Headquarters, 1958, with sun-shading louvers in the front facade (Source: E. J. Seow 1973)

Figure C-13
Kampong Bugis Design Guide Plan (DGP) proposal, with landscaped streets between building blocks (Source: Powell 1997)
Discussions With Akitek Tenggara For Bishan ITE

The following are abstracts from correspondences (in 2000) with the Akitek Tenggara for the design of Bishan ITE to confirm and expand various understandings already established from various sources:

"J. H. Bay" wrote:

Dear Kheng Soon and Patrick,

May Loke, Masters student, 2000, has run computer analyses (SOL-ARIS by Lam Khee Poh and Mahdavi) on the effectiveness of Bishan ITE large roof overhang and louvers for East and West façade and found that they were very effective (average 83% to 86%). This means that direct heat affects the façade only before 9am and after 4pm. I have run the same program for the corridors and found effectiveness to be similar. I have checked a previous study with measurements and found that heat levels in most of the non-air-conditioned rooms/spaces tested, when combined with available ventilation (plus aid of fans for certain classrooms) fulfill the thermal comfort index well. There is however some areas like the study corner, a few classrooms, the amphitheatre and landscaped street areas, which could be improved.

From Line, Edge and Shade (Powell 1997) and previous student interviews, I gather the salient points of precedents and thinking guiding the tropical design of Bishan ITE for our discussion. Please make any correction or further expansion if any.

Akitek Tenggara's position against the scaleless bland box and stronghold of 200 years of Western architectural training is succinctly expressed in Kheng Soon's paper Architectural Aesthetics of Tropicality, "One of the principal issues of designing in the tropics is the discovery of a language of line, edge, mesh and shade rather than an architecture of plane, volume, solid and void. An unlearning process..." Placing emphases on the roof with large over hangs to shade from the sun and rain, on lines, shadow and horizontality, subtlety of mesh, layers, inside-outside and in-between spatial possibilities in the façade, on profile and edge against cloudy sky, and on building sections taking precedent over
the plan as the generator of form and as the basis of design thinking. "In this time of rapid economic expansion, how do we design? ...What is the authentic response?" "A very sad thing is happening in architecture in that there is a lot of glossing over of the artifact. The historical motif is creeping back", (Patrick Chia 1996). There is the need to transform traditional (indigenous vernacular) climatic responses into contemporary technology, and a tropical aesthetic. Referring to Bishan ITE, ‘the language of line, edge and shade reached a new level of refinement’ (Powell 1997).

Referring to Bishan ITE, "The traditional Malay-Village-response to the tropical climatic is marvelous; they had breathing walls, monsoon windows, raised floors and the air just went through to provide a perfectly balanced climatic response. You have to resurrect the idea of cross-ventilation. You have to use large roof eaves, because you want shadows and protection from driving rain and you want to use the Venturi effect to accelerate the air flow and create comfort." "Basically, in the tropics, you need an 'umbrella' for a roof. You do not need to fight the elements. This is where the informality of Asian lifestyles comes out." "At ITE Bishan, we wanted to encapsulate a microcosm of the city in a tropical climate" (Patrick Chia 1996). Other admired precedent designs for climatic response include: The Singapore Scouts Association HQ by E J Seow Associates, 1959; The Singapore Conference Hall and Trade Union House, Malay Architect Co-Partnership, 1965; House in Binjai Park, Singapore, Lim Chong Keat, 1962.

I gather from the sketches for Kandang Kerbau Women's and Children's Hospital (1998) that detailed sectional and component studies were made, and therefore that a similar methodology was applied to Bishan ITE. From such sketches, you could graphically judge and make decision regarding climatic response. Kindly add points to the above general understanding of design thinking, precedents and guidelines if any.

Please help me answer the following questions in detail where possible. Where it is NOT possible, please indicate it is not possible. (It is common that when we judge and decide intuitively, we are not conscious of the thought processes or cannot
differentiate or remember. At other times we are very clear of what we thought.) (Please elaborate as much as you can.)

a. What did you recall specifically or referred to as guide(s) when you were designing Bishan ITE?

(It can be different things for different aspects or parts of the building. For instance, you could recall a particular precedent project or pictures in a book when you designed the large louvers, and you referred to something else when you designed the corridors, etc.)

b. Various aspects of the building work well climatically as well as aesthetically. How do you know it will work when you were designing?

We know sectional sketches with details of components were used to help the eye to judge and decide graphically. Were there rough calculations of angles, sizes, etc? Please describe the process of judging as best you can. (It will be most wonderful if you have old relevant sketches that I may make copies of, besides the already published drawings and pictures, so that I may use them also for illustrations.) I am very grateful for your time and kind assistance.

Towards better design understanding,
Yours truly,
J. H. Bay

"Patrick Chia" wrote:

The corridors came out of the need to create a teaching environment that allows student to focus and yet have good natural ventilation. Hence the integrated boxes with vents below and above. But since the concept Singapore has gone up market and many of the rooms were a/c. It is regrettable but the idea of the grille vents above and below the box is still a good one and can be used effectively in Singapore's natural ventilation context. Precedents - I don't remember major precedents the built form arose out of the need to create flexibility as teaching curriculum are undergoing tremendous change. But there cannot be infinite flexibility so flexibility is defined as allowing partition walls to be moved within a narrow band for cross ventilation - so the building
became two long and narrow blocks allowing for a street to be created at ground level - I hope this is some help. Your questions imply a certain design approach but I think in reality design is a creative process that is yet to be understood. The concept of precedents is only one of the ways but I think it is also influenced by the state and drive of the designer at the point of time. The intention is to create a microcosm of the community so that students can rehearse the roles of living and working in society - hence it reinforces the idea of a street.

Patrick Chia

"J. H. Bay" wrote:

Dear Patrick and Kheng Soon, Thank you for your kind response and additional information of Akitek Tenggara's thinking behind the design of Bishan ITE. From these one can see that designing is a complex process involving various mental reasoning and references immediate at the time of designing, and general guiding principles from past examples (precedents), concerning multiple criteria of flexibility, community of learning and living, environmental comfort, technology and aesthetic. I understand also that when Kheng Soon and you conceptualised and sketched Bishan ITE, the expert eyes and minds (no calculations) were used to judge graphically the adequacies of various aspect of the design. The creative process of design is indeed complex; varied and yet certain coherence is maintained, intuitive, playful and yet accurate most of the time. The minds combined as a team, are also capable of similar results. Much more is needed to understand this amazing aspect of the human mind. Thank you again for contributing to this continuing process of learning. Please feel free to drop me a line if you have any further thoughts and discoveries as we continue our journey.

Sincerely,
J. H. Bay


Result Of Environmental Survey On Rain Problem At Bishan Institute Of Technical Education

The responses from 40 persons interviewed are reflected as percentages to each answer. The respondents were students and staffs who are users of the institute, and most of the respondents were students. Where the rain is not a problem, the response is nil. The results for the survey are as follows:

1. How long have you been coming to this building complex?

   0% first time 0% less than 1 yr 90% 1-2 years 10% more

2. Please tick if you find it inconvenient because you get wet or may get wet in the following areas:

   a. Staircase next to the Lift, when the rain is

      0% very light 0% moderately light 70% moderately heavy 30% very heavy 0% nil

   b. Bridges connecting the building blocks, when the rain is

      0% very light 0% moderately light 80% moderately heavy 20% very heavy 0% nil

   c. Corridors around the Landscaped Street between building blocks, when the rain is

      0% very light 0% moderately light 0% moderately heavy 55% very heavy 45% nil

   d. Corridors On 2nd Storey, when the rain is

      0% very light 0% moderately light 0% moderately heavy 55% very heavy 45% nil
e. Corridors On 3rd Storey, when the rain is

|          | 0% very light | 0% moderately light | 0% moderately heavy | 55% very heavy | 45% nil |

f. Corridors On 4th Storey, when the rain is

|          | 0% very light | 0% moderately light | 0% moderately heavy | 55% very heavy | 45% nil |

g. Amphitheatre, when the rain is

|          | 0% very light | 65% moderately light | 35% moderately heavy | 0% very heavy | 0% nil |

h. Canteen, when the rain is

|          | 0% very light | 0% moderately light | 0% moderately heavy | 10% very heavy | 90% nil |

3. Are there other areas you have problems with rain? Please name the place(s) if any:

Passage way to the Canteen below the Staircase

You get wet or you may get wet and feel inconvenient, when the rain is

|          | 0% very light | 0% moderately light | 80% moderately heavy | 20% very heavy | 0% nil |

Staircase access to the Multipurpose Hall

You get wet or you may get wet and feel inconvenient, when the rain is

|          | 0% very light | 0% moderately light | 75% moderately heavy | 25% very heavy | 0% nil |
General comments given by respondents:

The rain problem from the gallery and foyer (Amphitheatre) is unacceptable. The regular daily assembly meeting has to be cancelled because of rain or signs of rain coming. Even in moderately light rain, water flows down the gallery seats and into the foyer. The corridor floors are very wet in heavy rain.

Other comments given by respondents:

The building looks very harsh like a factory, and the classrooms at the uppermost floor of the lower block are hot and uncomfortable in the hot period of May to August.

**Overall Observations From The Results**

From the results it is clear that the main inconvenient locations for the users, due to rain, is the Amphitheatre area and several circulation areas. Despite the large roof overhang provisions for the Amphitheatre area, protection from rain remains inadequate even for moderately light rain. Moderately heavy rain also affects the passages to the Canteen and Multi-purpose Hall. Users of circulation areas at the Staircase next to the Lift and Bridges connecting the building blocks are inconvenienced by moderately heavy rain. Slightly more than half the respondents indicated that rain was a problem at corridors on all floors in very heavy rain. Comments were that the floors tend to get very wet in very heavy rain.
APPENDIX D

Categories of architectural design norms

The table on the next page shows categories of design norms (Tzonis and Oorschot 1987) relating various factors.

Norms are requirements and goals. Higher norms constraints lower norms in various chains of imperatives. Tzonis, Berwick, and Freeman (1975) gave the following hierarchy of norms:

1. Relating to style of life with high standing imperatives of interest related to structure of human relation,

2. Laws of a society, codes and regulations,

3. General programmatic objectives and constraints like the goals of clients,

4. Architectural and engineering directives, and

5. Working drawings and instructions on site.
Categories of architectural design norms (After Tzonis and Oorschot 1987)

- Norms associated with monetary cost or benefit
  - Circulation cost
  - Cost of services
    - Energy
    - Maintenance
    - Cleaning
    - Grounds-keeping
    - Mechanical transportation
  - Space efficiency, used space/circulation ratio
  - Rentability
- Norms associated with individual comfort
  - Circulation discomfort
  - Disorientation
  - Lighting
  - Variety
  - Acoustical
  - Microclimatic
  - View
  - Cleanliness and sense of order
  - Contact with ground and green
- Norms associated with social aspects
  - Community
  - Privacy
- Mixed norms
  - Safety
  - Security
  - Intervening opportunities
- Norms of dynamic character
  - Flexibility
  - Change and growth
APPENDIX E

Samples and data of the cognitive experiment

In the left column of Figure E-1 are the samples shown to subjects described in Chapter 6 in the experiment where they rated on a scale of 0 to 10 for the combined adequacy of protection or effectiveness of shading of direct and diffused solar radiation, and sheltering from rain in Singapore. Since any building shelter will provide some kind of protection even at its worst, the rating will never be zero, the expected ratings will range from 1 to 10, where 10 is for a perfect protection, like the case of an opaque screen wall. The subjects were to judge graphically or visually with their eye and mind. All façades shown were assumed to face East for an equal basis of comparison in this experiment.

In the right column of Figure E-1 are the corresponding calculations of the predictions of effectiveness, which were not revealed to the subjects. The predictions were calculated with the computer software, called SOL-ARIS developed by Lam and Mahdavi (2000), for predicting the effectiveness of shading of direct and diffused solar radiation in Singapore. Edir and Edif represent effectiveness for shading direct and indirect solar radiation respectively. (IEdir and IEdif represent ineffectiveness). D = depth of shade, A = angle or slope of shade, H = height of vertical plane mid point of corridor or balcony space below the shades. This vertical plane represents the average vertical position of a human user in the space, and the proportion of protection or non-protection in that plane. The height of 2.9m, which is the lowest vertical height of all the samples, was used as a standard height for comparison of the relative effectiveness of protection across samples.

For ranking purposes, the ineffectiveness of shielding from rain (IIEr), where rain can come from various angles due to wind, is assumed proportional to the openness or exposure to the sky or ineffectiveness in shading diffused solar radiation.
radiation (Edif), and is therefore also expressed as a percentage. For simplification of the experiment, the direct effects from being wet by rain and the heat impact from solar radiations are assumed of equal importance to the subjects.

For ranking purposes, since direct solar radiation has the greater immediate effect of heat on the vertical surface (the body of the user in the space) then diffused solar radiation, a higher weighting is assumed on the effectiveness of shading from direct solar radiation over diffused solar radiation.

**Figure E-1**
Samples shown to subjects in experiment for rating of effectiveness of sun shading and rain shielding, against actual calculated effectiveness of sun shading of direct and diffuse solar radiation, and proportionate openness to rain exposure (Source: All photographs by the author)

<table>
<thead>
<tr>
<th>Samples</th>
<th>Calculated effectiveness (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Shown to subjects with large slide projection in lecture theatre)</td>
<td>(Calculations and ranking unknown to subjects)</td>
</tr>
</tbody>
</table>

**Colonial House (2nd Storey Balcony)**

| Edir =87-100%† |
| Edif =70-100% |
| D = 3.4m |
| A = 7° |
| H = 2.9m |
| IEr = 0 – 30% (nts) |

† The effectiveness of protection varies because these traditional spaces are equipped with canvas or bamboo blinds that can be lowered according to the level of protection needed. A totally lowered canvas provides in this case 100% shading of direct and diffused solar radiation, and rain. Of course there will be re-radiated heat, and other forms of heat that are not considered in this experiment. In this experiment, the samples shown were with
<table>
<thead>
<tr>
<th>Location</th>
<th>Shophouse (3rd Storey Balcony)</th>
<th>Catholic Junior College (2nd Storey Corridor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edir, Edif</td>
<td>Edir = 85-100%&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Edir = 88%&lt;sup&gt;3&lt;/sup&gt;</td>
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<td></td>
<td>Edif = 66-100%&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Edif = 75%</td>
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<tr>
<td></td>
<td>D = 1.4m</td>
<td>D = 1.7m</td>
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<tr>
<td></td>
<td>A = -32°</td>
<td>A = -30°</td>
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<tr>
<td></td>
<td>H = 2.9m</td>
<td>H = 2.9m</td>
</tr>
<tr>
<td></td>
<td>lEr = 0 – 34%</td>
<td>lEr = 25%</td>
</tr>
</tbody>
</table>

<sup>2</sup> Blinds fully rolled up. The shading from the railings will also add to the effectiveness of shading.

<sup>3</sup> Ibid. Shading from sidewalls, columns, and railings will also add to the effectiveness. Edir = 85% and Edif = 66% are conservative on the low side without adding these additional shadings.

<sup>3</sup> The East orientation was assumed for comparison in this experiment. The actual building facades with such corridors to classrooms predominantly faced North and South, where the effectiveness of shading approximates 95% for direct solar radiation. Additional shading by parapet wall/railing or vertical shading screens was ignored for simplicity of comparison.
Westlake Secondary School (3rd Storey Corridor)

Edir = 86%
Edif = 70%
D = 1.5m
A = --32°
H = 2.9m
Ier = 40%

Bishan Institute of Technical Education (3rd Storey Corridor)

Edir = 82%
Edif = 59%
D = 2.3m
H = 2.9m
Ier = 41%

Ayer Rajah Community and Service Centre (2nd Storey Corridor)

Edir = 74%
Edif = 38%
D = 1.0m
H = 2.9m
Ier = 62%

* Ibid. Shading from railing was ignored for simplicity of comparison.
Edir = 62%5
Edif = 12%
D = 2.1m, 1m
A = -15°, 0°
H = 2.9m
IER = 88%

Edir = 54%6
Edif = 1%
D = 1.8m
H = 10.8m, 2.9m
IER = 99%

[Edir, Edif and IER were calculated as a combination of the ineffectiveness of shading solar radiation, and openness to rain exposure for both East and West exposure.]

[Calculated based on the assumption of solar heat gain per year on the vertical plane, G. For direct solar heat gain per year, G = IEdir x total solar heat per day x 365 x area of vertical plane. Ga for vertical plane of height 2.9m = Gc for 10.8m – Gb for 7.9m (10.8 - 2.9m). Therefore, IEdira x 2.9 = IEdirc x 10.8 – IEdirb x 7.9. IEdirc and IEdirb are determined with the SOL-ARIS software, thus giving IEdira = 46%. Using the same formula, IEdifa = 99%.]
Figure E-2
Diagram shown as an example of drawing examining the operation of the shading devices, while posting the rebuttal mechanism: "Think of why the design may not work"

(Source: LPT Architects, Singapore 1999. LPT Architects used this sketch and many other similar drawings to ascertain visually the shading operation of the louvers. They looked for both the shading provided as well as the shading not provided, or why they may not work.)
Figure E-3  
Ratings of adequacy of sun and rain protection for Colonial House sample

<table>
<thead>
<tr>
<th>Colonial House</th>
<th>Control Test Rating</th>
<th>Warning Test Rating</th>
<th>Rebuttal Test Rating</th>
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<tr>
<td></td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
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<td>AA</td>
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Note: It is assumed that no test for debiasing in this time-tested example is required.

215
Figure E-4
Ratings of adequacy of sun and rain protection for Shophouse sample

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Mean: 6.7

Note: It is assumed that no test for debiasing in this time-tested example is required.
### Figure E-5
Ratings of adequacy of sun and rain protection for Catholic JC sample

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Figure E-6

Ratings of adequacy of sun and rain protection for Westlake SS sample

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Points: 0 0 6 12 30 120 84 24 9 0 285 0 0 9 16 30 106 77 24 18 0 282 0 0 9 8 40 84 77 48 27 0 293
Mean: 6.1 6.0 6.2

218
### Figure E-7
Ratings of adequacy of sun and rain protection for Bishan ITE sample

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**Vote-total**
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**Points**
0 0 6 4 20 0 2 12 12 1 40 84 83 56 9 0 3 78 0 9 0 24 75 60 70 24 0 0 262

**Mean**
6.6 5.9 5.6
## Figure E-8
### Ratings of adequacy of sun and rain protection for Ayer Rajah CSC sample

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| CSM | 1 | 1 | 1 |
| CYF | 1 | 1 | 1 |
| CE | 1 | 1 | 1 |
| CMH | 1 | 1 | 1 |
| CHT | 1 | 1 | 1 |
| CCS | 1 | 1 | 1 |
| CJ | 1 | 1 | 1 |
| CYK | 1 | 1 | 1 |
| CCL | 1 | 1 | 1 |
| CSH | 1 | 1 | 1 |
| CC | 1 | 1 | 1 |
| Fr | 1 | 1 | 1 |
| Fy | 1 | 1 | 1 |
| GWK | 1 | 1 | 1 |
| KB | 1 | 1 | 1 |
| KSK | 1 | 1 | 1 |
| KE | 1 | 1 | 1 |
| LE | 1 | 1 | 1 |
| LA | 1 | 1 | 1 |
| LM | 1 | 1 | 1 |
| LLS | 1 | 1 | 1 |
| LWK | 1 | 1 | 1 |
| LC | 1 | 1 | 1 |
| LCC | 1 | 1 | 1 |
| LHK | 1 | 1 | 1 |
| LKM | 1 | 1 | 1 |
| LWL | 1 | 1 | 1 |
| LYS | 1 | 1 | 1 |
| NSG | 1 | 1 | 1 |
| OLL | 1 | 1 | 1 |
| PJ | 1 | 1 | 1 |
| SL | 1 | 1 | 1 |
| STT | 1 | 1 | 1 |
| SPK | 1 | 1 | 1 |
| SSL | 1 | 1 | 1 |
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| TJ | 1 | 1 | 1 |
| TWS | 1 | 1 | 1 |
| THC | 1 | 1 | 1 |
| WKF | 1 | 1 | 1 |
| YYY | 1 | 1 | 1 |
| YP | 1 | 1 | 1 |
| Z | 1 | 1 | 1 |

Vote-total: 0 1 2 9 12 11 9 2 1 0 47 0 0 4 13 16 10 4 0 0 0 47 0 1 13 17 10 4 1 1 0 0 47 0 2 39 68 50 24 7 8 0 186
Points: 0 2 6 36 60 66 63 16 9 0 256 0 0 12 52 80 60 26 0 0 232 0 2 39 68 50 24 7 8 0 186
Mean: 5.5 4.9 4.2

220
### Figure E-9

**Ratings of adequacy of sun and rain protection for Balestier ITE sample**

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**Vote-total**

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**points**

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**Mean**

| 5.4 | 4.8 | 3.9 |
### Cognitive Biases in Design

**Figure E-10**

**Ratings of adequacy of sun and rain protection for Temasek Poly sample**

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Points: 0 6 12 56 65 48 21 8 9 | 0 225 | 1 4 12 56 65 54 21 8 0 0 221 | 1 2 10 30 48 45 36 7 16 0 0 | 194

Mean: 4.8 4.7 4.1
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231


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Cognitive Biases in Design


INDEX

Index of key concepts

Analogy, 2, 55-56, 66-68
Analytical approach, 52-53
Backing, 78, 123-124
Base, 78, 123-124
Biases, 1, 74-79
  due to imaginability, 2, 95-97, 116, 136-140, 158, 169-170
  due to representative-ness, 2, 93-95, 115, 131-136, 158, 168-169
  hindsight bias, 147
Case study, 6, 11, 80-81
  specific building, 102-118
Climatic comfort, 4, 16-21, 59-68
Cognitive experiment, 6, 81-82, 158-171
Cognitive structure, 122, 123
Conceptual system, 8, 78-79, 123-124, 126-141, 155
Debiasing, 5, 79, 143-156, 167-170
Decision making, 2, 50-58, 90-92
Descriptive thinking, 122, 153
Design, 2, 13-15
  grammar, 14
  guidelines, 45
  performance, 2, 108
  practice, 1, 21-43, 178
  problem, 44, 50-58
  thinking, 2, 50-58, 90-92, 179
  training, 2, 149, 178
Directive, 78, 123-124
Environmental control, 8, 17-21, 59-68, 108-112
Errors in design, 5, 45-47, 112-113, 115-117, 173-175
Fact, 78, 123-124
Heuristics, 1, 50-59, 74-79, 112-118, 173-175
  anchoring, 98, 117
  availability, 2, 95-97, 116, 129, 136-140, 169
  representativeness, 2, 93-95, 115, 129, 131-136, 168-169
Illusions, 1, 86-100
  misconception, 88-90
  human perception, 86-88
Judgement, 2, 44, 50-58, 90
Learning, 128-132, 137-139
Memory, 128-132, 137-139, 148
Mindset, 70, 143, 150
Morphology, 79, 125-141, 153-154
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norm, 78, 123-124, 211-212</td>
<td></td>
</tr>
<tr>
<td>Normative thinking, 122</td>
<td></td>
</tr>
<tr>
<td>Operation, 79, 125-141, 153-154</td>
<td></td>
</tr>
<tr>
<td>Outcome, 149-150</td>
<td></td>
</tr>
<tr>
<td>favourable, 149</td>
<td></td>
</tr>
<tr>
<td>negative, 149-150</td>
<td></td>
</tr>
<tr>
<td>Overconfidence, 6, 146, 158</td>
<td></td>
</tr>
<tr>
<td>Paradigms, 6, 31-43</td>
<td></td>
</tr>
<tr>
<td>Performance, 79, 125-141, 153-154</td>
<td></td>
</tr>
<tr>
<td>Precedents, 1, 50-68, 107</td>
<td></td>
</tr>
<tr>
<td>entities and properties, 113-114</td>
<td></td>
</tr>
<tr>
<td>problems, 69-71</td>
<td></td>
</tr>
<tr>
<td>problem solving, 50-58</td>
<td></td>
</tr>
<tr>
<td>in guidelines, 59-68</td>
<td></td>
</tr>
<tr>
<td>Pre-parametric thinking, 1, 57-58, 66-68</td>
<td></td>
</tr>
<tr>
<td>Prescriptive statement, 122</td>
<td></td>
</tr>
<tr>
<td>Probability, 93, 144, 147</td>
<td></td>
</tr>
<tr>
<td>Qualitative thinking, 1, 57-58, 66-68</td>
<td></td>
</tr>
<tr>
<td>Rational, rationality, 5, 57-58</td>
<td></td>
</tr>
<tr>
<td>'irrational', 140-141</td>
<td></td>
</tr>
<tr>
<td>Rebuttal, 8, 150-156, 158, 173-175</td>
<td></td>
</tr>
<tr>
<td>Recall, 128-132, 137-139</td>
<td></td>
</tr>
<tr>
<td>Representation,</td>
<td></td>
</tr>
<tr>
<td>framework of architectural knowledge, 8, 78-79, 125, 126-141</td>
<td></td>
</tr>
<tr>
<td>Rules-of-thumb, 1, 50-58</td>
<td></td>
</tr>
<tr>
<td>Simulations, 4, 65</td>
<td></td>
</tr>
<tr>
<td>Sustainability, 4, 59</td>
<td></td>
</tr>
<tr>
<td>Tropical architecture, 2,13</td>
<td></td>
</tr>
<tr>
<td>defining, 13-15</td>
<td></td>
</tr>
<tr>
<td>practice, 6, 21-43</td>
<td></td>
</tr>
<tr>
<td>Validity, 2, 93-95, 115, 123, 140-141, 135</td>
<td></td>
</tr>
<tr>
<td>Warning, 144, 158</td>
<td></td>
</tr>
</tbody>
</table>
ABOUT THE AUTHOR

Mr. Joo-Hwa BAY was born on January 23, 1959, in Singapore. He completed his architectural degrees at the School of Architecture, National University of Singapore, and in 1986 he started work with a small architectural firm. He later joined a large firm, SAA Partnership, Singapore, that gave him an opportunity to practice architecture in Papua New Guinea. In 1994, he became a company director of another large firm based in Singapore, Regional Development Consortium Architects (today known as RDC Architects Private Limited). He was involved in the designs of many small and large projects in the Southeast Asian tropical region, and in several competition winning schemes. In 1995, he started his own small practice and taught design at the School of Design, Temasek Polytechnic, Singapore. He was also actively involved in the discussion of various issues of practice and education as a council member of the Singapore Institute of Architects from 1994 to 1998. In 1997, he joined the Department of Architecture, School of Design and Environment, National University of Singapore as an academic staff, while maintaining his touch with the industry through his consultancy service. As chairperson to an editorial team, he helped the Singapore Institute of Architects publish a book entitled, *Contemporary Singapore Architecture: 1960's to 1990's*, in 1998. From the end of 1997 he had the opportunity to collaborate on a research with the Design Knowledge System Research Centre at the Faculty of Architecture, Delft University of Technology, the Netherlands.
The author investigates:

- The cognitive bases of illusions may lead to errors in design thinking.

- It is important to understand the context of such possible errors.

- A design tool can overcome this type of error through the introduction of a robust mechanism. The mechanism corrects bases and improves accuracy in architectural thinking.

The research method applied is interdisciplinary. It employs knowledge from cognitive science, environmental engineering, and architectural theory. The case study approach is also used. The investigation is made in the context of tropical architecture. The investigation of architectural bases differs from work by A. Toomée and D. Kinnunen in 1982 on heuristics and biases. According to Toomée and Kinnunen, the use of heuristics and stereotypes across different societies is subject to significant variability based on cultural and environmental factors. The judgements of probability can result in cognitive illusions of similarity and biases due to environmental factors, respectively. This theory can be used to improve the understanding of the structure of environmental factors. Various spatial configurations leading to description, standard performance, and error measurements are used to test the effect of different variables on the various spatial configurations.

The research is carried out within the framework of design theory developed by Design Knowledge System Research Centre, TU Delft.

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