# Ways of Experiencing Sustainable Design in Engineering: A Phenomenographic Investigation

By

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# STATEMENT OF AUTHORSHIP

The work presented in this thesis is, to the best of my knowledge and belief, original and my own work, except as acknowledged in the text, and that the material has not been submitted, either in whole or in part, for a degree at this or any other university.

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This research project was granted approval by the University of Queensland's School of Education Research Ethics Committee on 7 October 2004 (Ethical Clearance Number 04/55).

# ABSTRACT

An understanding of sustainable design will be essential for engineers to practice responsibly in the future. It is now also mandated by Engineers Australia's Graduate Attributes as an essential outcome of Australian engineering programs. What sustainable design means in practice, however, is a contested issue, varying between engineering disciplines, industry sectors and even individual practitioners. How then can both current professional engineers and engineering students learn about sustainable design?

This thesis reports on an empirical study to investigate qualitatively different ways sustainable design has been experienced by practicing engineers. The different ways of understanding sustainable design were found using a qualitative research method known as phenomenography. This research method revealed the critical variations in the ways twenty-two practicing engineers described their experiences of sustainable design. By examining the experiences of practitioners having to deal with sustainable design on a day to day basis, a clearer picture of sustainable design in practice was attained.

The twenty-two engineering practitioners were interviewed using semi-structured, open ended approach. The interviews were transcribed *verbatim*, de-identified, and analysed phenomenographically. Five qualitatively different ways of experiencing sustainable design were identified: sustainable design as 'solution finding', 'reductionist problem solving', 'holistic problem solving', 'social network problem solving', and 'a way of life'. Descriptions of each way of experiencing sustainable design are presented, including illustrative quotes from the practicing engineers and a hierarchy demonstrating the interrelationships.

By understanding the different ways practitioners have experienced sustainable design, recommendations are made for how to both improve the practice of sustainable design and the education of engineering students about sustainable design.

Implications for the practice of sustainable design include the need to:

- Focus on identifying clients' problems in collaboration with the clients themselves, rather than accepting a set of declared requirements;
- Identify and solve all design problems within a larger societal and environmental context;
- Understand that different people have different ways of experiencing sustainable design that will influence their actions.

Implications for improving the education of engineers about sustainable design include the need to:

- See professional development, including undergraduate education, as a combination of developing more comprehensive ways of experiencing practice, and skills development;
- Make explicit throughout engineering programs the focus on developing ways of experiencing the practice of sustainable design and engineering in general;
- Structure courses and programs around students reflecting on and challenging their own understanding of sustainable design, including from those experiences gained outside formal learning;
- Help students to develop more comprehensive ways of experiencing the practice of sustainable design;
- Locate skills development within the context of engineering practice;
- Develop academics' ways of experiencing sustainable design, to enable them to improve the learning experiences they offer their students.

The contribution of this thesis is in identifying the way practitioners see sustainable design practice. This can form the basis of a new model of professional development within engineering.

# List of Publications

Kellam, N., Addison, V., Maher, M., Mann, L. M. W., Radcliffe, D., & Peters, W. (2006). *The Faculty Perspective on the State of Complex Systems in American and Australian Mechanical Engineering Programs*. Paper presented at the 2006 ASEE Annual Conference & Exposition, Chicago, IL.

My Contribution: 5%. I aided in the Australian research for the paper.

Mann, L. M. W., & Radcliffe, D. (2003). *The Development of a Tailored Systems Engineering Process for Extracurricular Student Design Projects.* Paper presented at the 14th International Conference on Engineering Design, Stockholm, Sweden.

My Contribution: 85%. I conducted the research and wrote the paper. Radcliffe edited and revised the paper.

Mann, L. M. W., & Radcliffe, D. (2003). *Using a Tailored Systems Engineering Process within Capstone Design Projects to Develop Program Outcomes in Students*. Paper presented at the ASEE/IEEE Frontiers in Education Conference, Boulder, CO.

My Contribution: 85%. I conducted the research and wrote the paper. Radcliffe edited and revised the paper.

Mann, L. M. W., & Radcliffe, D. (2005). *A Reflexive Course for Masters Students to Understand and Plan Their Own Continuing Professional Development.* Paper presented at the 2005 American Society for Engineering Education Annual Conference & Exposition, Portland, OR.

My Contribution: 85%. I conducted the research and wrote the paper. Radcliffe edited and revised the paper.

Mann, L. M. W., Walther, J., & Radcliffe, D. (2005). *Sustainable Design Practitioners: Why They Must be at the Centre of Discussions on Sustainable Design Education.* Paper presented at the 2005 ASEE/AaeE 4th Global Colloquium on Engineering Education, Sydney, Australia.

My Contribution: 80%. I conducted the research and wrote the paper. Walther and Radcliffe edited and revised the paper.

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My Contribution: 80%. I wrote the paper. Millican and Richards edited and revised the paper.

Richards, P., Mann, L. M. W., & Millican, G. (2005). *Future Engineers Australia Management Project: Turning High School Students into Engineering Entrepreneurs*. Paper presented at the 2005 ASEE/AaeE 4th Global Colloquium on Engineering Education, Sydney, Australia.

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My Contribution: 15%. Walther conducted the research and wrote the paper. Radcliffe and I edited and revised the paper.

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Candidate Date

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Principle Advisor Date

*In memory of*

*Tim Allan (1984 – 2006),*
*who, in tragically taking his own life,*
*reminded me that we are but six and a half billion people,*
*all heading towards a fate of our own choosing,*
*one way or another.*

*and*

*Simon Vos (1981 – 2006),*
*who, in tragically passing away while doing something he loved,*
*reminded me that we should all be doing what we want to do,*
*rather than what we believe we have to do.*

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# TABLE OF CONTENTS

# LIST OF FIGURES



# LIST OF TABLES

# 1 INTRODUCTION

> *In the varied topography of professional practice, there is a high, hard ground overlooking a swamp. On the high ground, manageable problems lend themselves to solution through the application of research-based theory and technique. In the swampy lowland, messy, confusing problems defy technical solution. The irony of this situation is that the problems of the high ground tend to be relatively unimportant to individuals or society at large, however great their technical interest may be, while in the swamp lie the problems of greatest human concern. The practitioner must choose. Shall he remain on the high ground where he can solve relatively unimportant problems according to prevailing standards of rigor, or shall he descend into the swamp of important problems and nonrigorous inquiry?*
>
> *Donald Schön (1931–1997) (Schön, 1987)*

I chose to descend into the swamp, because I believe sustainability to be the greatest problem we have ever, or will ever, face. This thesis explores the variation in experiences of sustainable design in practice. The experiences with sustainable design of a group of twenty-two engineers and non-engineers were investigated empirically. This revealed five qualitatively different ways of experiencing sustainable design. These have implications for both improving future practice, and the education of students about sustainable design. This chapter details the focus of the study on sustainable design and the associated motivations behind it. The chapter also outlines the disposition of this thesis, in terms of the contributions it makes to various areas of study. Finally, the research questions for this thesis are presented, along with an overview of the structure of the thesis.

## 1.1 Focus of the Study

Sustainable design was chosen as the focus of this thesis as it provides a tangible way of working towards the goal of sustainability, as well as being more specific and grounded in engineering, compared to the notion of sustainable development. The focus is on design activities, as the key decisions and expenditure for a project occurs during the initial design phases (Burke, 1999). If the decisions made in these phases embed sustainable design in them, by better preparing the engineering student who will be working as designers in the future, then it will improve the overall outcomes of the project much more than in any other phase.

The fundamental problem with applying sustainable design in practice is that, like many aspects of professional practice, different people and different groups have different views of what sustainable design is. There is no commonly agreed to or shared understanding of what sustainable design means, and how it is operationalised in practice (Johnston, 1997; 2003). One reason for this is that everyone's own understanding is influenced by their own particular background, previous training, work experience and their political and economic setting (Leal Filho, 2000). These different views need to be identified in order to improve both the practice and the education of sustainable design.

The purpose of this thesis is to examine variations in the experiences of sustainable design among professionals involved in engineering design activities, including both engineers and non-engineers, using a phenomenographic approach (Marton & Booth, 1997). The emphasis is on the experiences of practitioners of sustainable design all with experience in engineering operations (Mann et al., 2005). These practitioners not only have to deal with sustainable design issues on a daily basis and so have many experiences to draw upon, but are also generally more aware of the current trends and applications of sustainable design in practice than other groups, such as engineering academics or policy makers (this point is discussed further in Section 2.4.1).

## 1.2 Motivations for the Study

All Australian engineering graduates are now expected to have a working understanding of sustainable design. This is not merely an expectation of professional institutions that accredit engineering programs (Engineers Australia, 2005), nor is it only limited to a few specific disciplines within engineering, but increasingly it is an expectation of the engineering workplace (Gale, 2005; Lang et al., 1999) as well as the wider society (Williams, 2002). This expectation presents a series of motivations for investigating experiences of sustainable design to aid in improving both practice and education.

### *1.2.1 Professional Motivation*

The engineering profession has been confronted with the need to integrate sustainability and sustainable design into their practice, from international engineering groups (see, for example World Engineer's Convention, 2004), industry groups within Australia (see for example Minerals Council of Australia, 2002), and Australian State and Federal Government policy (Environmental Protection Agency, 2003; Productivity Commission, 1999). They have also become part of the main agenda of professional engineering bodies both in Australia and overseas. It must now become an agent of sustainable development (Elms & Wilkinson, 1995). Doug Jones (2003), a past president of Engineers Australia stated that sustainability needed to become part of every professional engineer's conduct and ethical framework. He argued that sustainability is the dominant paradigm shift in engineering at the moment, and urged its promotion in the training of engineers. Historically, engineering has been an agent of development.

Following Jones' comments, there were calls to define what exactly sustainability meant for engineers (Day, 2003). Many engineers agreed, and were unsure of what sustainability, sustainable development and sustainable design entailed for engineers, both in scope and attainability. Questions were asked such as: Is it that the world's population is unsustainable or that the material use in most engineering projects is unsustainable? Is it intergenerational or intragenerational sustainability, or both? Is it on a time scale of 50, 100 or 1000 years? Are the knowledge and values associated with sustainable design and development something that students could learn in a sequential manner within a course or two, throughout their entire program, or something else?

Within the engineering industry, there is now a greater awareness of the benefits of using a sustainable approach. A study in the UK found that fifty-five percent of senior executives saw sustainable design as the most important mechanism for their companies to deal with sustainability issues (Datschefski, 2001). More and more, engineering companies are measuring their performance using sustainability metrics (Harding, 1999). From the standpoint of operations, a sustainable approach carries with it potential savings of resources, both technical and economic. Many companies are using sustainable development opportunities to lower their operating expenses, thereby increasing their profitability (Vesilind et al., 2006).

Taking a sustainable approach is also seen by some companies as providing a competitive advantage over their competitors, enabling them to take advantage of rapidly expanding opportunities in an increasingly competitive industry (Vesilind et al., 2006). Other companies see incorporating sustainability into their operations as a public relations opportunity, developing the company's reputation in the community and giving them a social licence to operate and promoting community harmony (Harding, 1999; Hargroves & Smith, 2005). This idea is echoed in the sustainability reports put out by many engineering companies in Australia (see for example (Thiess, 2006)).

This adoption of sustainability within industry indicates that unless engineers and engineering programs embrace sustainability and specifically sustainable design, they will be increasingly left out of key decision making roles in business and industry (Harding, 1999). However, the integration of sustainability and sustainable design into the engineering profession has been problematic, as many engineers currently lack the necessary knowledge, skills and attitudes required to shift to sustainability (Crofton, 2000; Kellam et al., 2006). The way to address this shortfall is with professional development, for current practicing engineers and in enriching engineering programs at universities across Australia that are creating future professional engineers. It is imperative that changes in education occur to enable engineers to meet the challenges of sustainability and sustainable design in the future (Crofton, 2000).

## *1.2.2 Educational Motivation*

Engineering accreditation bodies around the world have moved towards outcomes based accreditation systems over the past ten years (IEAust, 1996; Mann & Radcliffe, 2003b; Walther et al., 2005). These accrediting bodies have moved to specify lists of attributes that graduates are to have acquired by the end of their engineering programs, rather than just learning specific content and passing exams (McGourty & Shuman, 1999). The attribute lists, while specified by individual accrediting bodies, were developed through a consultation process involving universities, industry and the Engineering profession (IEAust, 1999). Two lists of these 'graduate attributes' are presented in Table 1 (ABET, 2002; IEAust, 1999).

**Table 1: Engineers Australia's and ABET's Graduate Attribute Lists**

| **Engineers Australia's Graduate Attributes** | **ABET's Program Outcomes** |
|---|---|
| i) An ability to apply knowledge of basic science and engineering fundamentals | a) An ability to apply knowledge of mathematics, science, and engineering |
| ii) An ability to communicate effectively, not only with engineers, but also with the community at large | b) An ability to design and conduct experiments, as well as to analyse and interpret data |
| iii) In-depth technical competence in at least one engineering discipline | c) An ability to design a system, component, or process to meet desired needs |
| iv) An ability to undertake problem identification, formulation and solution | d) An ability to function on multi-disciplinary teams |
| v) An ability to utilise a systems approach to design and operational performance | e) An ability to identify, formulate, and solve engineering problems |
| vi) An ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a team leader or manager as well as an effective team member | f) An understanding of professional and ethical responsibility |
| vii) An understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and for the need for sustainable development | g) An ability to communicate effectively |
| viii) An understanding of the principles of sustainable design and development | h) The broad education necessary to understand the impact of engineering solutions in a global and societal context |
| ix) An understanding of and commitment to professional and ethical responsibilities | i) A recognition of the need for, and an ability to engage in life-long learning |
| x) The expectation of the need to undertake lifelong learning, and capacity to do so | j) A knowledge of contemporary issues |
| | k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice |

The first set of attributes is from Engineers Australia (EA), formally the Institution of Engineers Australia (IEAust), which is the main accreditation body for engineering programs in Australia (IEAust, 1999). The second set is from the Accreditation Board for Engineering and Technology (ABET) (2002), who accredit engineering programs in the United States of America. ABET use the terminology 'program outcomes' instead of graduate attributes, but there is no difference in intent.

These sets of attributes have been compared and contrasted, and a hybrid set of attributes developed, in order to identify similarities and differences between the different international views (Mann & Radcliffe, 2003b). These can be seen in Table 2 with their associated mappings. Although it has been agreed that the lists of graduate attributes have been a step in the right direction, they were developed more as aspirational attributes than with any particular pedagogy in mind (IEAust, 1996). The graduate attributes have lead to a new focus on the attributes engineering graduates require in today's global society, including broader knowledge, skills and values (Mann & Radcliffe, 2003b).

**Table 2: Mapping of Graduate Attribute Lists**

| Hybrid Attribute | EA Graduate Attribute | ABET Program Outcome |
|---|---|---|
| Application of basic science and engineering | i | a |
| Communication skills | ii | g |
| In-depth technical competence | iii | ~k |
| Problem identification, formulation and solution | iv | e |
| Design and conduct experiments | - | b |
| Systems approach to design | v | c |
| Teamwork | vi | d |
| Social, cultural, global & environmental awareness | vii | h,j |
| Sustainability | viii | j |
| Professional & ethical responsibilities | ix | f |
| Lifelong learning | x | i |

One theme common to these two lists and indeed many other recent lists of attributes produced by engineering accreditation bodies is an understanding of sustainable design and development within a global context (ABET, 2002; IEAust, 1999). The lists state that engineers should have an understanding of their social, cultural, global and environmental responsibilities, and should understand the need for sustainable design and development. However, this leaves many questions unanswered. What is sustainable design in engineering, particularly in an Australian context? What are the responsibilities of engineers with respect to sustainable development? Is there one underlying meaning that needs to be uncovered, or is all we can hope for a contextual understanding, dependent on where sustainable design is to be applied and who is applying it? Without addressing these questions, how can it be said that a graduate has developed these attributes?

Further, there is a question of whether or not the current teaching and learning practices in engineering education are able to incorporate value laden and complex concepts such as sustainable design (Johnston, 2003). In order to instil these graduate attributes within students, learning objectives must first be developed that detail what it is that the students are expected to learn. For topics in engineering that have been well defined over a long period of time, such as dynamics and fluid mechanics, this is a straight forward process (Besterfield-Sacre et al., 2000). However, since issues such as sustainable design impact such a diverse group of stakeholders, this thesis argues that it is only by looking at the diverse ways that sustainable design has been experienced in practice, that we can hope to develop a working understanding of sustainable design for educational purposes. The reason for this is summarised by Pieter Van Der Gaag from the Northern Alliance for Sustainability (OECD, 2001):

> *To achieve sustainability, information and dialogue from all actors in society is needed. By increasing the complexity of the information used in decision making, by adding the different perspectives of the stakeholder groups through, for example, multi-stakeholder dialogues, societies can be protected from decisions based on prejudiced, one-sided, and untested theory.*

To find out how to educate engineering students, we need first to find out what current professional engineers' experiences of sustainable design are. Engineering education is a professional education, and thus aims to enable students to engage in practice in ways characteristic of competent engineering practitioners (Dall'Alba, 1993). We cannot simply rely on academics' current knowledge or the current literature on sustainable design to inform educational processes, as the practice of sustainable design is changing at an ever increasing pace (McLennan, 2004). We must turn to the people who are having both to deal with sustainable design on a daily basis, and who are recognised as leaders in the field. We must look to practitioners of sustainable design and their experiences to help inform the future of engineering education about sustainable design (Mann et al., 2005).

Further, we need to stretch the horizons of current engineering practice, and examine the variations in experiences of sustainable design of both engineers and non-engineers. While all still involved with engineering design activities, these practitioners are not confined to a 'culture' of engineering practice and can offer different insights into and perspectives of what sustainable design is and could be.

A final educational motivation for this study concerns the 'lead time' of students into professional practice (Thom, 1998). Up to a decade may have elapsed by the time changes are made to engineering curricula at a universities and a cohort of students have moved through the new program, graduated and subsequently become practicing engineers,. By this time, the problems around sustainability and sustainable design that engineers will face will be further advanced and more complex. Thus, changes to engineering education need to happen rapidly and be across all levels, including undergraduate, postgraduate and professional.

### *1.2.3 Societal Motivation*

In the past few decades, society has become more informed and questioning about sustainability. "Historically, the engineering profession has not been perceived by society as being particularly concerned with the environment, [however] society now recognises that unchecked development also leads to environmental harm" (Williams, 2002). It can be argued that it is engineers' support for development and society's concern for the environment that is one factor in the public's low esteem of engineers today compared to earlier times (Elms & Wilkinson, 1995; Williams, 2002). "All engineers now have a responsibility to consider the principles of sustainability as well as ensuring that their activities are environmentally sound and sustainable" (Williams, 2002, p1). As a profession, engineers have responsibilities to society, and since society is concerned about sustainability and sustainable development, then engineers should not only have the ability to design sustainably, but value the need for it also.

The societal motivation for looking at sustainable design in engineering is also part of a larger crisis in confidence in the professions first identified by Schön (1983). "Professionally designed solutions to public problems have had unanticipated consequences, sometimes worse than the problems they were designed to solve" (p4).

The result has been a general questioning by society of the professional judgement and autonomy previously taken for granted. Society has started to question at a deeper level, professions such as engineering's "claim to extraordinary knowledge in matters of human importance" (p5). This has lead to governments placing more emphasis on the accountability of professionals such as engineers in sustainability matters, and forced the increased transparency of environmental and social decisions made by engineers (Harding, 1998). Sustainability is a major matter of human concern, and as such, it is important that engineers try to regain societies trust in dealing with sustainability issues. The final societal motivation concerns society as a whole. As AtKisson (2001, p7) argues:

> *We have the power to fundamentally shape climate, manage ecosystems, design life-forms, and much more. The fact that we are currently doing these things very badly obscures the fact that we are doing them, and can therefore learn to do them better. Designing and managing the world is now our responsibility.*

## 1.3 Disposition of the Thesis

This thesis contributes to two fields of research: (i) investigating the practice of sustainable design, both generally and in engineering, (ii) investigating the education of engineers about sustainable design.

(i) This thesis investigates variations in practitioners' experiences of sustainable design. There are many implications of these variations to the practice of sustainable design, including making sustainable designers more aware of their own practice, as well as helping to restructure future practice to make it more sustainable. There are also implications on an individual, group, and organisational level.

(ii) The education of engineers about sustainable design is at the core of this thesis. To explore how to create future engineering professionals, this thesis examines practicing engineers and non-engineers who design for sustainability. As the field of sustainable design is changing so rapidly, people dealing with sustainable design issues on a daily basis are able to contribute a large range of experiences. Also, practitioners in other non-engineering fields will have relevant experiences in engineering operations that can add positively to understanding sustainable design in practice. The variations in practitioners' experiences have implications for sustainable design education in engineering. These include the need for learning to be structured around students moving from less to more comprehensive ways of experiencing the practice of sustainable design.

Along with these, this thesis adds to the application of the phenomenography within engineering as a useful way to investigate aspects of engineering practice, and to help inform future engineering education efforts.

# 1.4 Thesis Questions

Based upon the focus, motivations and disposition for this thesis discussed so far, the research questions are:

1. What are the variations in ways of experiencing 'sustainable design' among sustainable design practitioners?
2. What are the implications of this variation for the practice of sustainable design?
3. What are the implications of this variation for the education of future professional engineers about sustainable design?

# 1.5 Structure of the Thesis

This section provides an overview of the rest of the thesis, structured around the planning and implementation of a phenomenographic study of practitioners' experiences of sustainable design.

**Chapter 2** introduces a review of some of the current literature of sustainable design and sustainable design education in engineering. A general overview of sustainability is introduced first to provide an overarching framework for the study. This is refined to examine sustainable design as a concrete way of moving towards the goal of sustainability, particularly for engineers. Current sustainable design education efforts are presented and reviewed also, to help position the study within practice and education.

In **Chapter 3**, a general overview of the research approach used in this study is presented. The way an aspect of the world is experienced is discussed first. An overview of phenomenography is presented, including a brief history of the approach along with some previous studies that have used phenomenography. The chapter also details the object of study as the relations between the persons and aspects of the world, and describes the outcomes of a phenomenographic investigation as a set of qualitatively different ways of experiencing an aspect of the world and the relationships between them. A more detailed examination of the method is presented, including the processes for the collection and analysis of the data. Finally, issues of validity, reliability and generalisability in phenomenography are discussed.

The research approach is expanded upon in **Chapter 4**, which describes the design and analysis processes within the phenomenographic study. The development of the context is presented, including details of the decisions that shaped the final study and led to a focus on sustainable design practitioners' experiences. A pilot study in the form of a workshop is described, along with the implications for the main study derived from this pilot. The design of the main study is then presented, including the processes for the selection of the final twenty-two sustainable design practitioners and the diversity of the group. The data collection process is also discussed, including the interview process and protocol used to obtain the practitioners' experiences of sustainable design. The analysis process from individual ways of experiencing sustainable design to developing the final categories of description is described, along with the processes for ensuring the validity and reliability of the results. Finally, the ethical considerations of the study are discussed, including obtaining the participant's informed consent, and the need to de-identify and keep confidential the data obtained.

The results of the study, five qualitatively different ways of experiencing sustainable design, are described in **Chapter 5**. The outcome space and an overview of the results are presented first. The five categories of description are then described in detail, including illustrative quotes and diagrams. The relationships between the categories are then presented, along with the distribution of subjects across the categories.

The implications of the thesis results for both the practice and the education of sustainable design are discussed in **Chapter 6**. A discussion of the wider use of phenomenography in engineering research is presented. Finally, possible future investigations are proposed.

**Chapter 7** concludes the thesis, and includes a summary of the findings and answers the initial research questions.

# 2 A REVIEW OF THE LITERATURE

*We didn't inherit the Earth from our ancestors — we are borrowing it from our children.*

*- Very old Pacific Islander saying*

## 2.1 Introduction

“The rational pursuit of sustainability, global or otherwise, is only possible if we know what sustainability is or, more exactly, if we know what we want to sustain and in what respect” (Tisdell, 1990, p1). One of the aims of this thesis is to begin to develop this understanding, specifically of sustainable design within engineering operations. To do this, the starting point needs to be sustainability and sustainable development to establish the necessary context for the investigation. This chapter examines what is known and understood by the terms ‘sustainability’, ‘sustainable development’ and ‘sustainable design’ in practice and in engineering education at present. It provides not only a necessary backdrop to the research in this thesis, but serves as a framework for discussing the results of the phenomenographic investigation of sustainable design practitioners’ experiences also.

Section 2.2 provides an overview of sustainability from both a global view as well as an engineering standpoint. Section 2.3 focuses on the current practice of sustainable design, including some of the general principles, as well as some a focus on the sustainable design process. Finally, some of the current efforts at educating engineers about sustainable design are presented in Section 2.4.

# 2.2 Towards the Goal of Sustainability

> *To… prevent global collapse, we need an idea that is both visionary and profitable, a solution that can appeal to both the ardent altruist and the hardened venture capitalist. We need a source of hope that is also a business opportunity, a hot investment that is also intensely idealistic. We need something that will challenge our higher natures and attract our basic instincts, coaxing us into the game of transformation without polarizing society or fomenting revolution. We need something that has not been seen since humans first began plowing up dirt, building skyscrapers, and messing around with atmospheric chemistry. We need something that has the power to command a lifetime of allegiance, even though it does not truly exist yet in practice and may never fully exist except in theory. We need something we can barely begin to describe in tangible, concrete terms. But fortunately, we have a word for it.*
>
> *(AtKisson, 2000a, p130)*

## *2.2.1 A Global View of Sustainability and Sustainable Development*

At the core of this thesis are the concepts of sustainability and sustainable development, and how they translate into engineering practice. Sustainability in general refers to a state that can endure indefinitely. Specifically, it has come to mean the long-term survival and wellbeing of both human and natural systems (AtKisson, 2001). Sustainability is the goal, and sustainable development is the path or framework to that goal (Harding, 1998). The differences between sustainability and sustainable development are further summarised by Jahnke and Nutzinger (2003):

- 'Sustainability' is understood to be a general regulative idea that initiates and accompanies a process of learning and searching; whereas
- 'Sustainable development' is a more concrete notion, in principle leading to practical measures.

Jahnke and Nutzinger (2003) also remark that it is difficult to make the notion of sustainability more practical. On one hand, if it is made more concrete and precise, then the openness towards the future inherent in the concept of sustainability is lost. On the other hand, if this concept is vaguely defined then it cannot serve as a reasonable heuristic choice for searching for various paths toward sustainable development. It has been argued that the vagueness of its definition thus far has hindered its widespread application, particularly in engineering (Harding, 1999). This is one reason why we must look toward sustainable development and specifically, sustainable design and to provide practical principles for engineers to use.

The World Commission on Environment and Development' *Our Common Future* (1987) provides the most widely accepted definition of sustainable development:

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

While the term 'needs' requires clarification, it is clear that it is development for the present that does not adversely impact the future. It is a concept that implies action, either to reverse the degradation of the environment or to reduce impacts to society from engineering projects while still maintaining economic growth. Sustainable development is not however development-as-usual with "a few green looking additions or nods to social equity" (AtKisson, 2001, p9).

From an Australian perspective, sustainable development has been termed 'ecologically sustainable development' by the Australian Government in their *National Strategy for Ecologically Sustainable Development* (Commonwealth of Australia, 1992). This was in part due to pressure from non-governmental organisations (NGOs) who were concerned that without this focus, the *National Strategy* would be dominated by economically sustainable development (Harding, 1999). Specifically, the *National Strategy* defines ecologically sustainable development as "using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased" (Commonwealth of Australia, 1992, p4).

Sustainable development places emphasis on meeting the needs of the world's current population, or intragenerational equity, as well as the needs of future generations, or intergenerational equity (Pearce, 1989). How can we describe what the needs of the future are, and how do they compare with the needs of current generations? One suggestion is to use the available natural resources as a measure, and that sustainable development should not result in negative natural capital degradation, or damage to the environment (Pearce, 1989). While this would be an option, it is not always feasible. It is difficult to clarify what damage means, and does not take into account the social or economic dimensions of sustainable development.

Another suggestion is that, rather than having no reduction in natural capital (environmental resources), "future generations [could] be compensated for reductions in the endowments of resources brought about by the actions of present generations". This includes capital endowments, as well as a human capital endowment, or increases in scientific and technological knowledge (Pearce, 1989). This allows for development and resource use, so long as future generations are not disadvantaged.

Other important aspects of sustainable development include the precautionary principle and the conservation of biodiversity (Harding, 1999). The precautionary principle essentially states that a lack of scientific evidence alone is no excuse for inaction on environmental problems (Perdan, 2004). The conservation of biodiversity refers to the conservation of "the different plants, animals and micro-organisms, the genes they contain and the ecosystems of which they form part" (Harding, 1999, p5).

Sustainable development includes three identifiable dimensions: environmental sustainability; economic sustainability; and social sustainability. These are collectively referred to as the triple bottom line and form the basis of most sustainability reporting throughout the world (SustainAbility, 2004). The environmental dimension refers above all to the management and stewardship of natural resources. The economic dimension relates to the efficient use of resources, as well as economic viability. The social dimension relates to human health and welfare, and can include such things as labour opportunities, equal opportunities between social groups and society's ethical concerns. The social dimension also includes the traditional concerns of health and safety that engineers have already been required to integrate into their practices (Crofton, 2000).

Another critical aspect of sustainable development is the dichotomy between growth and development. In his book, *Believing Cassandra*, AtKisson (2000a) argues within sustainable development that while growth must cease, development must accelerate. In the past, these concepts have been understood to mean the same thing. For sustainable development, AtKisson argues, they must now become separated. Growth is seen as the increase in human population, resource use and the generation of waste. Development, however, is the improvement of human technology and wellbeing, including "health, education, intelligence, wisdom, freedom, and the capacity to love" (p24).

Traditionally growth has been linked to the concept of economic growth which is measured by the Gross Domestic Product (GDP) of an area or country. As AtKisson points out however, the term growth is misleading in this context, as the GDP measures the circulation of money, which is generally tied to the production of more and more goods. The growth of money is not the problem, but the growth of commodities is. GDP emerged as a measure of growth when natural resources seemed limitless and when a high quality of life was equated to a high economic standard of living. "But if prosperity is judged only by increased economic activity, then car accidents, hospital visits, illnesses (such as cancer), and toxic spills are all signs of prosperity" (McDonough & Braungart, 2002, p36-37).

An example of growth as a misleading concept that is often cited is the case of the Exxon *Valdez* oil spill (McDonough & Braungart, 2002). When it happened in 1991, the oil spill actually increased Alaska's GDP. As people from around the world went to help clean up, restaurants, hotels, shops and other businesses experienced an upturn in economic exchange. So while the accident led to more death of wildlife than any other human-caused disaster in US history, in terms of growth, the disaster was beneficial.

In simple terms, the dichotomy between growth and development can be resolved by equating growth with increases in quantity, and development with increases in quality (AtKisson, 2000a). Sustainable development that is based on these ideas of growth and development carries with it two fundamental assumptions: i) there are limits to growth, and ii) there are no limits to development. The first point is based on the Earth being a closed system, and can thus only support a finite number of people. While this number may increase due to technological developments, it is not infinite. This idea was first put forward by the Club of Rome in their book *The Limits to Growth* (Meadows et al., 1972), which was one of the beginnings of the current environmental movement. The second point implies that "the way we live can always be made better: more beautiful, more inventive, more creative, more efficient, more fulfilling" (AtKisson, 2000a, p25). "We cannot go on, and we cannot stop. We must transform" (AtKisson, 2001, p3).

### *2.2.2 An Engineering View of Sustainability and Sustainable Development*

All engineers must take a lead role in sustainability and sustainable development (Elms & Wilkinson 1995). Sustainability now forms the framework through which all engineering activity must take place (Harding, 1999). Sustainability in engineering not only spans all traditional engineering disciplines, but must transcend these traditional discipline boundaries to be effective in the future (Abraham, 2006). It must include traditional engineering disciplines working together along side other fields, including architecture, science, social science, philosophy, business and political science.

Engineering is no longer based on scientific or technical areas only. Instead engineering now operates within a broader social, environmental and political and global context (Harding, 1998; Kellam et al., 2006). Further, the decisions made are not entirely objective or value-free. Instead, different people can have different interpretations of the same situation based upon their beliefs and values. This idea is taken further by Melhus (2006, p223), who argues that:

> *The contemporary engineer often works in an environment where many people have opinions on and can influence whether an engineered solution is the correct one to pursue, even if its technical attributes are beyond question.*

Harding (1998, p3) posits that disagreements over environmental issues arise from:

- different perceptions of the same situations;
- the selection of information considered relevant to an issue (particularly an overly narrow selection or interpretation of the scientific data);
- failure to appreciate the social, political and values context of environmental issues and consider the concerns of the community.

While these are posed within environmental decision-making, it is argued that these disagreements are equally valid within the realm of sustainable design. Many sustainable design decisions have an environmental component, and many of the above factors can be generalised to other social settings, in particular, different people having different perceptions of the same situation (Åkerlind, 2005a). This idea that different people will have different perceptions about the same situations or about what is considered the 'problem' is of particular importance to this thesis.

Harding (1998, p3) argues that even if the best efforts are made, disagreements still occur, because peoples' perceptions and viewpoints are often based on "deep-seated strongly held value positions which are not reconcilable". However, a process that includes input from various stakeholders in the earlier stages of a project is beneficial. He argues that by revealing the possibly contrasting views of the client, the community and other stakeholders early in the process, changes can be made before too much money and time have been committed going down a particular path (p4).

While different people have different value and belief systems about sustainability that affect engineering, including engineers themselves, these systems are constantly evolving (Harding, 1998). These shifts can be due to changes in cultural beliefs, lessons learnt from past experiences, changes in technology, or changes in underlying knowledge. It is important then to be aware of these changing value systems within engineering.

While sustainability and sustainable development provide a general overarching framework, engineers require specific concepts and principles for practice. Currently in engineering, there is a move towards developing specific content, tools and techniques to help apply sustainability principles in practice (Carew & Mitchell, 2001; Paten et al., 2004). The prevailing thought is that to help practice, engineers need more and enhanced knowledge, skills and tools. Others argue that peoples' value systems need to change. If these are changed then other aspects, such as knowledge and skills, will change as a result (Harding, 1998). This thesis takes a different approach, and looks to understand how professionals act in practice (Dall'Alba, 1993; Dall'Alba & Sandberg, 1993; 1996). This approach is further explained in Section 2.4.

## 2.3 Current Practices of Sustainable Design

> *In many ways, the environmental crisis is a design crisis. It is a consequence of how things are made, buildings are constructed, and landscapes are used. Design manifests culture, and culture rests firmly on the foundation of what we believe to be true about the world.*
>
> *Sym Van Der Ryn (McLennan, 2004)*

Sustainable design is one of the major challenges confronting engineering. While many claim to be doing sustainable design, it is still unclear what is actually meant by the term, what it incorporates and what it does not. Some professionals see sustainable design as the addition of some environmentally or socially beneficial features to a traditional design, or trying to reduce the environmental and social impacts of a current design. Others see it as a completely new framework for doing design, and for designs to help regenerate environmental and social systems (McLennan, 2004). One of the reasons behind this confusion is that sustainable design is a movement that is actively defining itself, its principles, components and philosophy (McLennan, 2004). "Like any immature individual, sometimes it seemingly contradicts itself or seems unclear or even irrational" (p3).

This section presents an overview of sustainable design used throughout the thesis, along with a set of six principles and some of the processes within sustainable design. It contains a synopsis of best practice in sustainable design, distilled from the many different views that exist. It is not however a review of specific lists of principles to use in a step by step design process (see for example (Abraham & Nguyen, 2003; Anastas & Zimmerman, 2003; 2006; Datschefski, 2001)). The review is broader, and written to help frame the results of the thesis as different ways of experiencing sustainable design.

### *2.3.1 What is Sustainable Design?*

Sustainable design differs from traditional design in its results, its rationale and its processes (McLennan, 2004). In order to explore the question 'what is sustainable design?' traditional design is discussed first, along with some of the changes that have occurred in moving to sustainable design.

The traditional design process in general is cyclic in nature, where designers work back and forth between a set of needs or requirements and a series of interim solutions until a final solution is found (McLennan, 2004). Traditionally the requirements of a design centred on cost, functionality, safety and aesthetics, with little attention paid to the wider implications of the design. Design was based upon a linear, cradle to grave paradigm. Raw materials are extracted and made, manufactured into products, transported to consumers to use, then disposed of in a 'grave', usually in landfill (see Figure 1). This type of design paradigm dominates modern design and manufacturing; by some accounts more than ninety percent of materials extracted to made products for end users become waste almost immediately, with the product itself often not lasting much longer (McDonough & Braungart, 2002). It is often seen as cheaper to buy a new product than repair an old one. Further, many products in this paradigm are even designed with a planned obsolescence, designed to be used by a consumer for a few years then discarded for the 'new' model.

The first change to this traditional design paradigm in moving toward sustainable design occurred with the focus on eco-efficiency. While it can be argued that eco-efficiency had its roots in early industrialisation (McDonough & Braungart, 2002), it has been since the 1992 Rio Earth Summit and Agenda 21 (United Nations, 1993) that industries across the globe have started to embrace the concept. It was officially coined as a term by the Business Council for Sustainable Development in 1997 (McDonough & Braungart, 2002).

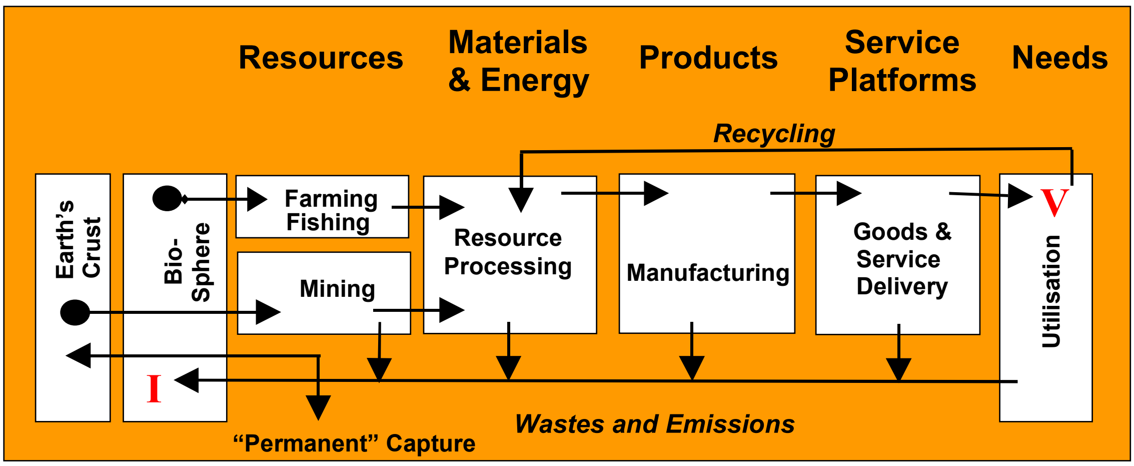


**Figure 1: Model of Eco-Efficiency**[1]

[1] From Dr Joe Herbertson, The Natural Step Australia

Eco-efficiency itself is based on the idea of doing more with less, doing more with the resources that are consumed, generating less waste and pollution, using renewable rather than non-renewable resources, and trying to minimise the harmful affects on human health and the environment (McDonough & Braungart, 2002). All resources come from either the Earth's crust or the Bio-sphere, as seen in Figure 1. They are then processed into raw materials, used in manufacturing systems to create goods and services, then transported to consumers to be used. At the end of use, goods are either recycled, or placed back into the Earth's crust in landfill, or into the Bio-sphere as pollution. Eco-efficiency tries to maximise the utilisation of goods and services (V), while minimising the impact to the Earth's crust and the Bio-sphere (I).

In their book *Cradle to Cradle*, McDonough and Braungart (2002) question the goal of efficiency in "a system that is largely destructive" (p63). Destruction, they argue, is generally more visible and easier to stop, whereas efficient destruction is harder to detect and thus harder to stop. From a philosophical point of view, "efficiency has no independent value: it depends on the value of the larger system of which it is a part… if the aims are questionable, efficiency may even make destruction more insidious" (p65). Efficiency can be good, but only within an overall system that is replenishing, rather than destructive. As long as humans and their systems are seen as being 'bad' (see, for instance Datschefski, 2001), then the ultimate goal of eco-efficiency is zero: zero wastes, emissions and 'ecological footprint' (Chambers et al., 2000). But, as McDonough and Braungart (2002) ask, what would it mean to be 100 percent good?

One outcome of this thinking is eco-effectiveness. "You might start to envision the difference between eco-efficiency and eco-effectiveness as the difference between an airless, fluorescent-lit gray cubicle and a sunlit area full of fresh air, natural views, and pleasant places to work, eat, and converse" (McDonough & Braungart, 2002, p76). Eco-effectiveness is about working on the right things, products and systems, rather than trying to make the 'wrong' ones less 'bad'. "It is far more powerful to design a process that does not require energy than one that has been optimized to use as little energy as possible" (McLennan, 2004, p88). Eco-effective design expands the scope under consideration from the primary purpose of a product or system to consider the whole, what its goals and potential effects are, both immediate and wide-ranging, with respect to both time and place. This is considered within the entire system – societal, economic and environmental – where the made thing, and way of making things, are parts. From an eco-effective paradigm, designs should include (McDonough & Braungart, 2002, p90-91):

- Buildings that produce more energy than they consume and purify their own waste water;
- Factories that produce effluents that are drinking water;
- Products that, when their useful life is over, do not become useless waste but can be tossed onto the ground to decompose and become food for plants and animals and nutrients for soil; or, alternately, that can return to industrial cycles to supply high-quality raw materials for new products;
- Transportation that improves the quality of life while delivering goods and services;
- A world of abundance, not one of limits, pollution, and waste.

Building on this, McLennan (2004) puts forward the following definition of sustainable design: "Sustainable Design is a design philosophy that seeks to maximize the quality of the built environment, while minimising or eliminating negative impact to the natural environment." Sustainable design is seen as a philosophy, an approach to design that can be applied to any object or project. It tries to enhance quality which as McLennan (p5) argues is about "creating better buildings for people, better products for our use and better places to inhabit". The purpose of design, he argues, is to create physical artefacts that benefit people, and sustainable design tries to do that using a wider, more holistic approach. Finally with the definition, he argues that the ultimate goal of sustainable design is not just to reduce the impact of the design on the environment, but to either remove it all together, or to go a step further and have a restorative effect on the environment.

## *2.3.2 Six Principles of Sustainable Design*

Six governing principles can be identified within sustainable design (McLennan, 2004):

1. The biomimicry principle;
2. The human vitality principle;
3. The ecosystem / bio-region principle;
4. The 'seven generations' principle;
5. The conservation and renewable resources principle;
6. The holistic thinking principle.

These principles provide a paradigm in which engineers and designers can operate to "design products and services to meet societal needs with minimal impact on the global ecosystem" (Abraham, 2006, p8). While the set presented here is from McLennan (2004), it can be argued that the six incorporate other sets of principles, such as those put forward in *Natural Capitalism* (Hawken et al., 1999) the *Natural Step: System Conditions* (AtKisson, 2000a; The Natural Step, 2005), and other similar sets (Abraham, 2006; Datschefski, 2001).

**1. The Biomimicry Principle**, or, respect for the wisdom of natural systems. This principle of sustainable design is based upon the idea of biomimicry, summarised in Janine Benyus's book *Biomimicry* (2002, originally published in 1997). The term comes from the Greek *bios*, meaning life and *mimesis*, meaning imitation. Biomimicry identifies that all of nature's innovations have the nine things in common, they: run on sunlight, use only the energy they need, fit form to function, recycle everything, reward co-operation, bank on diversity, demand local expertise, curb excesses within, and tap the power of limits. Benyus argues that these, along with the idea of the beauty of a design, will become a new set of rules for sustainable design. Biomimicry is also one of the four strategies of *Natural Capitalism* (Hawken et al., 1999).

McLennan (2004) argues that Biomimicry in some ways encompasses the other five major principles of sustainable design. All designs should aim to emulate natural systems, as somewhere in the world a creature or a natural system has already solved the problem under consideration (Benyus, 1999). Biomimicry has three major components:

1. Nature as model;
2. Nature as measure;
3. Nature as mentor.

Seeing nature as a model implies that ideas and inspiration for designs should be taken from natural systems. For example, looking at the skin of sharks to develop a new range of elite swimming suits, or using the water repellent properties of a lotus leaf to keeping water off car windscreens. Another example of nature as a model was the invention of Velcro from looking at how certain types of seedpods grip animal fur (Pahl & Beitz, 1996). Nature as a measure uses natural systems to judge the 'rightness' of designs (Benyus, 2002). Evolution has made nature find out already what works, what is appropriate and what lasts, and these ideas can help evaluate sustainable design efforts. An example of this would be comparing the efficiency of a solar cell to the efficiency of a leaf at converting sunlight to energy. Finally, nature as a mentor involves the change from seeing nature as a source of raw materials, to seeing it as a mentor, as a source of ideas. "The Biomimicry Revolution introduces an era based not on what we can *extract* from nature, but what we can *learn* from her" (Benyus, 2002, p2).

In the end of her book, Benyus proposes a four step path to achieve biomimicry (Benyus, 1999; 2002): (i) Quieting human cleverness, (ii) Listening to nature, (iii) Echoing nature, and (iv) Protecting the wellspring of good ideas through stewardship. The first step involves re-immersing ourselves in nature and acknowledging that nature knows best, achieving a connection with and an understanding of natural systems that we have lost in the past two hundred years. As Benyus (2002, p288) remarks:

> *For a long time we thought that we were better than the living world, and now some of us tend to think that we are worse, that everything we touch turns to soot. But neither perspective is healthy. We have to remember how it feels to have an equal standing in the world.*

Listening to nature involves 'interviewing', as Benyus terms it, all the flora and fauna on Earth to "discover their talents and survival tips, their role in the great web of things" (Benyus, 2002, p289). These interviews will help us to match the problems we are designing for with natural systems that hold the answers. Echoing nature involves trying to mimic what we find in nature (Benyus, 1999), which will require multidisciplinary and transdisciplinary activities to bring together engineers, designers, biologists and other groups to solve problems together. Finally she argues that we must become stewards of the natural systems that need to become our mentors:

> *Once we see nature as a source of inspiration, a mentor, our relationship with the living world changes. We realize that the only way to keep learning from nature is to safeguard naturalness, which is the source of those good ideas.*

**2. The Human Vitality Principle**, or, respect for people. This principle identifies that the whole point of designing is to create things for people. As such, designs should respect the physical, cultural and spiritual needs of people. "Sustainable design endeavours to create the healthiest, most nourishing places possible for people without diminishing the ability of nature to provide nourishing places for the rest of creation and for our own species in the future" (McLennan, 2004, p46). It is about respecting wholeheartedly the unique needs of people and honouring the diversity among people.

People need to be at the centre of designs. Many 'sustainably designed' products in the past that were designed to be better for the environment ended up being poorer for people, either physically or emotionally (McLennan, 2004). An example of a physical impact on people from design is that of sick building syndrome, which developed as a side effect of some energy efficiency measures initially implemented as part of sustainable design. Some of these measures lead to unhealthy indoor environmental conditions, when buildings became 'tighter' to become more efficient, effectively sealing in the internal environment. Indoor pollutants were trapped inside at greater concentrations than in the past and made people sick. Older buildings avoided this because of the greater infiltration, or leaks and drafts. A lot of the pollutants that built up causing sick building syndrome were Volatile Organic Compounds (VOCs), from new furniture, paints, carpet and other finishes. Efforts have been made since to reduce the amount of VOCs allowable in materials for buildings.

From an emotional standpoint, sustainable design asks questions about our relationship with our designs. "What makes people happy? Productive? What factors … allow us to perform our work efficiently and with gusto? What factors inhibit such behaviour?" (McLennan, 2004, p48). Designs should not only respect the physical needs of people but also the emotional needs. An example of this is in the design of hospitals, that up until recently have made people feel sicker being in them.

McLennan (2004, p49) also argues that sustainable design has a spiritual dimension within the principle of respect for people: “The reason why many in the design professions are finding ways to introduce the sustainable design principles into their practices is because on some level they know that it is the right thing to do”. The former Vice President of the US Al Gore (1992, p368) in his book *Earth in the Balance* echoes this argument:

> *The more deeply I search for the roots of the global environmental crisis, the more I am convinced that it is an outer manifestation of an inner crisis that is, for the lack of a better word, spiritual ... what other word describes the collection of values and assumptions that determine our basic understanding of how we fit into the universe?*

The human vitality principle also includes the need to change to a service and flow economy, one of the four strategies of *Natural Capitalism* (Hawken et al., 1999). While the point of designing is for people, what is designed needs to change. Hawken et al. argue for a shift in economy from one of goods and purchases to one of service and flow. “An economy that is based on a flow of economic services can better protect the ecosystem services upon which it depends” (p10). This idea involves leasing or renting goods instead of buying them outright; buying a service rather than a product.

An example of this is Interface Carpets who lease a floor-covering service rather than just selling carpet (Interface Corporation, 2006). Traditional carpet needs replacing every decade or so as it wears out, which entails buying a whole new carpet and disposing of the old one, usually in landfill. Interface changed this model to leasing floor-covering systems, as people want to “walk on and look at carpet, not own it” (Hawken et al., 1999, p139). The company retains ownership of the carpet, is responsible for keeping it clean and fresh and removing it at the end of its life in return for a monthly fee. What is also different is that they company moved from a traditional wall to wall carpet to tiles that can be replaced as they wear out. This means that instead of having to replace the entire carpet when, for instance, a walkway is worn, they just replace those tiles. Thus durability becomes a concern of the company providing the service, rather than the customer.

**3. The Ecosystem Principle**, or, respect for place. Sustainable design is built on the idea of regionalism, and honours the differences between places and the communities that inhabit them (McDonough & Braungart, 2002). The idea of place has been developed to describe the "complex interplay of climatological, biological, geological and topographical features that create the differences we see around us" (McLennan, 2004, p52). Respect for place demands that designs indeed differ not just from place to place, but from community to community and even individual to individual. It can be argued that western society has lost its respect for place and become disconnected from nature and the environment. This has allowed us to make design decisions without realising the impacts we are having.

Having respect for place includes looking for the local natural systems to solve design problems before technical fixes are applied. An example of this would be designing and orienting a new building to use prevailing breezes for cooling, rather than using air conditioning. Through a respect for place, the environmental impacts of designs are often diminished. This involves harnessing natural systems that differ from place to place and as such, reduce the design's reliance on technical fixes involving added energy and materials.

The ecosystem principle also encompasses the fourth strategy of *Natural Capitalism* (Hawken et al., 1999), that of investing in natural capital. This tries to reverse the decline in natural capital, or resources, living systems and ecosystem services through "reinvestments in sustaining, restoring, and expanding stocks of natural capital, so that the biosphere can produce more abundant ecosystem services and natural resources" (p11). A study of the world's ecosystem services and natural capital has estimated that the value of these services is of the order of thirty-three trillion dollars US annually, compared to a world GDP in the order of eighteen trillion dollars US (Costanza et al., 1997). Without reinvesting in natural capital, many of these services will continue to decline at an increasing rate.

**4. The 'Seven Generations' Principle**, or, respect for the cycle of life. This principle acknowledges that we are part of a larger cycle of life and death that has been occurring for millions of years and as such, this principle is perhaps the simplest and yet the most difficult to grasp (McLennan, 2004). It acknowledges that we are part of this cycle, and when we interrupt it, we create problems for both ourselves and the environment.

An example of the cyclic nature of life is the concept that in nature, every waste that is generated by something becomes food for something else (Hawken et al., 1999). We are the only species capable of producing waste, as all outputs from natural systems become food for other systems (Datschefski, 2001). The idea that waste equals food is an idea put forward by both Hawken, Lovins and Lovins (1999) in their book *Natural Capital: The Next Industrial Revolution*, and McDonough & Braungart (2002) in their book *Cradle to Cradle: Remaking the Way We Make Things*.

Respect for the cycle of life means that we need to incorporate the principle of waste equals food into design. As McLennan (2004, p66) asks, "What compels us to design packaging that lasts for a thousand years when the food contained in it is meant to last for a few days?" Currently we overengineer things that do not need to last, but under engineer the things that do. "Our greatest sin is this overengineering – we may not be able to live forever, but we make darn sure that our waste will" (Benyus, 2002, p126). For example, a single plastic bag may last thousands of years and be used once, but household items such as refrigerators, radios and even cars are designed with 'planed obsolescence' in mind. "Huge amounts of energy and resources are used to create objects that should be useful for decades, but instead, like their over-engineered counterparts, end up in the landfill in short order" (McLennan, 2004, p66).

Respect for the cycle of life means finding an appropriate balance between the life expectancy of a product and its use. If a product is to be thrown away soon after it is used, then it should quickly become food for other systems. It also means that we must look to create our products to fit within this cycle. As Benyus (2002, p97) points out:

> *Nature can't put its factory on the edge of town; it has to live where it works. As a result, nature's first trick of the trade is that nature manufactures its materials under life-friendly conditions – in water, at room temperature, without harsh chemicals or high pressures … The inner shell of the … abalone is twice as tough as our high-tech ceramics. Spider silk, ounce for*

*ounce, is five times stronger than steel. Mussel adhesive works underwater and sticks to anything, even without a primer…. Bone, wood, skin, tusks, antlers and heart muscle – miracle materials all – are made to live out their useful life and then fade back, to be reabsorbed by another kind of life through the grand cycle of death and renewal.*

Sustainable design realises that the effects of the decisions made today may last for generations; it's not about choosing between the lesser of two evils, but about choosing the 'right' solution.

**5. The Conservation Principle**, or, respect for energy and natural resources. It can be argued that respect for energy and natural resources is at the core of today's environmental problems, as we live in a world of finite resources, but we act as though they are infinite (McLennan, 2004). Two aspects of this principle are energy use and resource use.

In one way or another, all the energy that we use came from the sun at some point in the past. We are the only species that uses combustion as the source of energy for locomotion, which is an amazingly inefficient source of energy. Currently, in terms of energy use, the US economy for example is less than ten percent efficient, and wastes approximately three hundred billion dollars each year from this inefficiency (McLennan, 2004). Within sustainable design, the conservation principle recognises that energy is a valuable resource, and that we have a responsibility to use as little energy as possible within our designs while at the same time trying to maximise their quality.

The resource aspect of the conservation principle concerns how we manage and use the natural resources in our society, including water, metals and plastics. It recognises that all natural resources have an intrinsic value, and that the whole industrial economy is a subset of the natural economy (McLennan, 2004). The more the natural economy is degraded, the more we degrade the basis of our own economic health. The conservation principle states that "we have a responsibility to use as little of any resource as is necessary for a given job without sacrificing the project's quality and the long-term availability of that resource" (p83). This principle also embodies the principle of *Natural Capitalism* regarding the need for radically increased resource productivity (Hawken et al., 1999).

This principle embodies the idea of considering the usage of resources over their entire life cycle, as a material may have a low environmental impact in one phase of its life, but a higher impact in another. It also includes the idea of using renewable resources instead of non-renewable ones. Renewable resources are harvested and extracted no faster than they are replenished by nature, and include, for example, a sustainable timber plantation.

**6. The Holistic Thinking Principle**, or, respect for process. This principle of sustainable design deals with the way the processes within design are conducted. It is based on the idea that "if we want to change a result, we must first change the process that led to the result" (McLennan, 2004). It is imperative that we change our current design processes, as it is not possible to create sustainable solutions to problems that we face now with the way we have designed in the past. Traditional design used a reductionist approach, with systems broken down into components and sub-components, each designed, then put back together. Sustainable design instead takes a holistic approach, and not only looks to keeping a sense of the whole throughout the design process, but also considers the broader impacts on society and the environment of the designs. The holistic design process is discussed further in Section 2.3.3.

The principle of respect for process contains six sub-principles (McLennan, 2004):

1. A commitment to collaboration and interdisciplinary communication;
2. A commitment to holistic thinking;
3. A commitment to life-long learning and continual improvement;
4. A commitment to challenging rules of thumb;
5. A commitment to allowing for time to make good decisions;
6. A commitment to rewarding innovation.

(1) Sustainable design requires increased communication and integration among disciplines, as it is rare that one individual or discipline has the "capacity to create design solutions that are robust enough to meet all the requirements for a project to be sustainable" (p88). Focusing on using only specialists in sustainable design often limits the ability to come up with innovative solutions and often eliminate contextual issues from the problem solving process (Johnston, 2003). While an understanding of the intimate workings of specific engineering skills is still required, people with this focus

still need to be taught different ways of thinking to be able to design sustainably. As McLennan (2004, p89) argues “sometimes the people who know the most about the field often overlook the simple questions and solutions to problems”.

(2) A commitment to holistic thinking requires challenging conventional thinking processes in design and broadening the issues considered. It does not require that we know everything about a system, but that we acknowledge what we do know and understand and what we do not (McLennan, 2004). Section 2.3.3 discusses holistic thinking in more depth, as it forms the basis of the sustainable design process.

(3) The area of sustainable design is constantly changing and growing as new systems, technologies and ways of operating develop. This requires a commitment to continual improvement and life-long learning, not only to keep up with current trends, but to develop greater synergies between knowledge domains (McLennan, 2004). It is not enough to consider knowledge in isolation, instead holistic thinking considers that all knowledge is connected, as other realms of knowledge may contain answers to the problems under consideration. As the cliché goes, ‘the more you know, the more you realise you don’t know’.

(4) Many environmental problems are created by a system that was set up without regard to the environmental impacts it causes. An example of this is the use of ‘rules of thumb’ in engineering and design. Engineers often use standard systems and components as a rule of thumb, rather than trying to select an option that has a lower environmental impact or questioning how appropriate it is to the given situation. Rules of thumb can be a barrier to creativity and innovation in design. While it is inefficient to redesign every system each project, rules of thumb need to be questioned and tested to see if they can be applied in a given situation (McLennan, 2004). For example, rather than specifying a standard size air conditioner for a new building, a commitment to challenging rules of thumb would involve seeing if a smaller unit would be sufficient, or trying to incorporate passive cooling systems into the design to reduce the size air conditioner required.

(5) A commitment to allowing for time to make good decisions allows time for additional things to happen that are important for sustainable design, such as more design meetings among the different disciplines involved, or more research into different systems or materials that may have a better environmental performance (McLennan, 2004). The pace of the project should still be as fast as possible, but giving more time reduces the mistakes often caused by a rushed process.

(6) Finally, “engineers must be rewarded for the efficiency of their designs, not just their sufficiency” (McLennan, 2004, p95). Too often in society currently, mediocrity in designs is rewarded while innovation is scorned. For practitioners to embrace sustainable design there must be a commitment to rewarding innovation.

### *2.3.3 The Sustainable Design Process - Holistic Thinking*

The sustainable design process is different from traditional design in four ways (McLennan, 2004):

1. It requires a willingness to do things differently to the past;
2. It requires expanded collaboration between disciplines;
3. It requires adhering to an ‘Order of Operations’;
4. It requires key decision makers to use a holistic thinking process.

(1) Sustainable design requires more of a change in process than a change in materials or technologies. But from an engineering perspective, it is far easier to substitute a sustainable material or technology to replace an old one, than it is to change the process of design. But this change of process is necessary, as a larger range of issues need to be considered often in the same time as traditional design. This requires a different approach, as designers cannot rely on conventional solutions that have worked in the past.

(2) As the issues that need to be considered in sustainable design are greater and more varied, and often in areas that engineers do not have expertise in, a greater deal of collaboration is required. Engineers must work together with other disciplines in an interdisciplinary fashion (McDonnell, 2000).

(3) Sustainable design also involves a change in process with respect to the order in which design elements are considered (McLennan, 2004). This 'order of operations' involves four steps: (i) Understand the place where the design will be situated; (ii) Reduce the loads on the design; (iii) Make use of free energy; and (iv) Use the most efficient technology possible. The first step involves understanding the local conditions where the design will be located, including climate, temperature and other effects that may impact the design. This step also relates to the ecosystem principle (Section 2.3.2) and recognises that different locations may have different characteristics and thus may require different designs. Reducing the loads on the design, the second step, includes reducing the system requirements for the design involving energy or materials, seeing if some can be reduced or eliminated entirely. Making use of free energy, the third step, also aims to reduce the required energy of the design. The final step then looks to technical solutions to problems that are chosen to be as efficient as possible.

To explain the idea of the order of operations further, consider the design of a solar power unit for a house, in this case in the US (McLennan, 2004, p216):

> *If a typical homeowner desired to take his or her house off the grid or provide one hundred percent of its power through photovoltaics on an annual basis without following the* ***order of operations****, the owner may need to spend anywhere between twenty-five to thirty thousand dollars to do so because the typical American home is incredibly energy wasteful…*
>
> *However, following the Order of Operations has a dramatic effect on the outcome. If such homeowners first examine their climate and place [Step 1] they would better understand where exactly to position the solar panels and at what angle to maximize its harvest and reduce the payback of the system… the individual homeowner would then examine the entire home's electrical loads [Step 2] and seek to reduce them. The homeowner might decide to switch all interior lighting to compact fluorescents and to replace the refrigerator and water heater with highly efficient models at an additional first cost… The next step [Step 3] would be to use free energy wherever possible which might include understanding when to open windows for natural ventilation to reduce summer cooling loads and providing external shades to further block heat gain.*
>
> *After all of these things are done, the homeowner, by following the Order of Operations, is finally ready to purchase solar panels [Step 4]. To his or her surprise the owner would likely find that the new cost to achieve the same goal of providing one hundred percent of power from PV had dropped … to between ten and twelve thousand dollars.*

(4) The sustainable design process is based upon holistic thinking, also referred to as systems thinking (Olson, 2006). One reason for this is that holistic thinking broadens the traditional ways of approaching problems. Engineers have traditionally focused on immediate and observable phenomena to reduce the number of variables in solving a problem. This reductionist approach in design has caused many unintentional effects on surrounding systems in the past (McDonough & Braungart, 2002; Olson, 2006). As Einstein famously remarked "Without changing our patterns of thought, we will not be able to solve the problems we created with our current patterns of thought". Sustainable design seeks solutions to problems by (Abraham, 2006, p6):

> *Looking outside the scope of the process or product being developed and considering the system as a part of the global ecosystem, which includes all humanity. The sustainable engineer will be asked to design processes that do not specifically maximize profit, but rather maximise benefits, defined based on all of the elements of the triple bottom line.*

Sustainable design is also based upon holistic, systems thinking as the Earth itself, as well as every object on Earth, can be thought of as a large complex system (Clayton & Radcliffe, 1996; Olson, 2006; Russell et al., 2006). Without taking a holistic, systems approach, designs cannot be fully integrated into the natural systems that encompass all human systems. The approach also identifies that the systems of the Earth are highly non-linear; small or seemingly unimportant events can have major effects on the system. Thus in holistic thinking, elements cannot be removed or considered in isolation from the whole system, the approach that traditional design is based on. This is because the smallest changes in one part of the system can have major effects in another part of the system (Clayton & Radcliffe, 1996).

Instead, holistic thinking attempts to widen the circle of understanding around a problem in order to understand the connections between elements within and outside of the traditional design space, as everything is connected to everything else (McLennan, 2004). While this circle of understanding cannot be widened to infinity, it is about trying to find the essence of the problem, and make decisions that ripple outward from the problem to positively impact the surrounding social, environmental and economic networks. As McLennan (2004, p219) describes, this holistic process still includes the scientific process but in a different way:

*Instead of drawing a tight boundary around what is relevant, it acknowledges this boundary and then attempts to expand it until it can not any longer, and then and only then zooms in on potential. The result, surprisingly, is often more efficiency as well as more clarity and long-term success. Fewer mistakes are made as more is considered.*

Designs that are produced using holistic thinking are examples of integrated designs. "Integrated design solutions are those that simultaneously solve several problems within the one solution and embody the work and requirements of multiple disciplines" (McLennan, 2004, p222). Integrated designs also are more robust against value engineering, which traditionally removes sustainable features from designs to meet budget constraints. If a conventional design had sustainable 'add-ons' such as solar panels or a grey water system, these are usually the first to be removed during the value engineering process. Truly sustainable designs are only achieved using holistic thinking to produce integrated solutions.

## 2.4 Sustainable Design Education in Engineering

*Effectively including this complex web of considerations within engineering curricula presents no small challenge. Engineers and engineering students will feel most comfortable with the technical 'components', with aspects that are readily quantified and with the 'systems' approach that may be used to show linkages and process. They are likely to feel far less comfortable with the values-based social aspects, matters that cannot be readily quantified and with analysis of the higher order 'drivers' of sustainability.*

*(Harding, 1999, p7)*

Sustainable design is seen as a core professional engineering competence for the purposes of this study. Thus, this review of the literature on the current thoughts and practices of sustainable design education is in relation to the development of professional engineers. This view of professional development includes students at universities, both undergraduate and postgraduate, and professional engineers. In a university setting, engineering education's main objective is to produce engineering graduates that can engage in practice as competent professionals (Dall'Alba & Sandberg, 1996). In a professional setting, the main objective of professional development is to maintain up-to-date technical skill, and knowledge of process, technology and legislation (Engineers Australia, 2003).

Traditionally, both formal university education and professional development have entailed defining specific attributes, including knowledge, skills, attitudes and values (Dall'Alba & Sandberg, 1993; 1996). Education is seen as the cumulative acquisition of these attributes, also known as skills development (Dreyfus, 2002; Dreyfus & Dreyfus, 1986). An alternative view to professional development is based on the existence of different ways of experiencing practice (Dall'Alba & Sandberg, 1996; 2006). "The knowledge and skills that make up professional practice are organized within an understanding of that practice" (Dall'Alba, 2004, p680). Thus professional education is seen as both enriching experiences of engineering practice (Dall'Alba, 1993), as well as developing skills within the context of practice (Dall'Alba & Sandberg, 2006). These combine to form a 'professional way-of-being'.

### *2.4.1 Current Sustainability and Sustainable Design Education*

In the past, "changes in curricula initiated by educational institutions, have ranged from little, to course adaptation, to a few bold efforts to equate education to the new situation [of sustainability]" (Thom, 1998, p90). Sustainable design education at university is often seen as an add-on to existing engineering courses and programs, rather than an integral part of the curriculum (Crofton & Mitchell, 1998; Harding, 1999; Paten et al., 2004). A reason for this approach often cited is the belief that little could be left out of existing curricula to make room for new courses on sustainability and sustainable design (Thom, 1998). While some universities in Australia have made efforts at embedding sustainability and sustainable design at the core of their engineering curricula, these are usually only in one or two specific disciplines, rather than across all engineering (Thom, 1998; Williams, 2002). It is necessary that all engineers have an understanding of sustainable design; it is not an area that can and should be left to any specific discipline within engineering.

One of the reasons for the add-on approach to teaching sustainability and sustainable design is that many see them as consisting of a set of content to be learnt, principles to be applied, or a set of tools to be mastered (Paten et al., 2004). Others also see them as incorporating a value component, but one that can be separated from the knowledge and skill components (Carew & Mitchell, 2001; 2002). Some universities have developed a set of learning outcomes for their graduates about sustainability and sustainable design, matching this breakdown into knowledge, skills and values (see for example the University of NSW (Institute for Environmental Studies, 1999)). Further, Harding (1999) proposes four ways of integrating sustainability and sustainable design in to engineering curricula, as:

- Components which may separately involve technical, economic, social or environmental elements;
- Higher order elements including policy, legislation, industry drivers;
- Integration between the components and the higher order elements;
- Value-based interpretations.

Most engineering teaching however "is still about the technological solution of technical problems, not about the context of the application of technology, now a clearly signalled societal expectation" (Thom, 1998, p89). One study in particular has separated learning about sustainability into specific knowledge, skills, awareness, attitudes and participation (Nguyen & Pudlowski, 1999). Of particular interest is the identification of awareness, attitudes and participation within sustainability. Awareness refers to developing students' awareness of sustainability issues, the idea being that students who are more aware of issues will be more in a position to learn about sustainability. Attitudes refer to a set of values and feelings for sustainability issues. The study does not specify what attitudes students need to develop, only that the development of their own attitudes is important. Finally, participation includes providing an opportunity for students to be actively involved in sustainability based projects to both learn in practice and further develop their awareness and attitudes.

Recently a 'critical literacies' program has begun to be developed that could be used across engineering programs in Australia as the basis of sustainability and sustainable development education (Hargroves & Smith, 2005; Paten et al., 2004). This system, known as the Engineering Sustainable Solutions Program, developed by The Natural Edge Project (2006), is designed to be used by academics to complement existing courses in university engineering programs. It can also be used by companies in a workshop format for professional development purposes. The program is made up of a set of 'critical literacies', or pieces of information about sustainability along with a set of case studies to provide examples of the critical literacies in practice (Paten et al., 2004). There are a set of modules ranging from entry level and more advanced topics, with each module made up of technical units that can delivered in a workshop or traditional lecture format. The modules are supported with the Natural Edge Project's book, *The Natural Advantage of Nations* (Hargroves & Smith, 2005).

The structure of sustainability and sustainable design education in Australia is primarily based on the understandings of the specific academics charged with developing and delivering courses at universities across the country (Carew & Mitchell, 2003). The way each academic understands sustainability and sustainable design will impact on the approach they take to teaching their students. The way they understand and value them will be both the framework from which they are able to teach, and impact the type of role model they provide for their students (Crofton & Mitchell, 1998).

Further, the ways academics see the field of engineering may be different to the way they see the specific part of engineering they are teaching (Dall'Alba, 1993). For instance, "they may see their own field as consisting of dynamic and creative ways of interpreting some aspect of the world but see their course content as selected information to be presented to students" (p302). A study investigating thirty-five academics ways of seeing the content of a course of study found three distinct categories (Dall'Alba, 1993), course content as: i) a body of knowledge and skills, ii) concepts and principles to which knowledge and skills are linked, and iii) experiences of a field of study and practice. The study concluded that how academics view and teach a field of study will have an effect on the experiences that students have of the courses and the field of study.

As an example of how academics' understanding of sustainability influences their teaching practices, a recent study of eight engineering academics (Carew & Mitchell, 2003) found four 'metaphors' they used to describe and discuss sustainability:

- **Sustainability as weaving** – seeking to understand and draw together technical and non-technical elements to create a cohesive but flexible whole;

- **Sustainability as guarding** – guarding and apportioning exploitable resources and waste sinks to ensure that they are not depleted too rapidly and/or are distributed equitably;
- **Sustainability as trading** – quantifying the environmental and/or social and/or economic costs and benefits of a decision and trading them off against each other;
- **Sustainability as observing limits** – recognising the existence, interconnectedness and limits of systems, and following a hierarchy in observing/applying system limits.

While this study focused on sustainability in general, it can be argued that a similar list could be developed of academics' understandings of sustainable design. From these metaphors, if a particular academic saw sustainability as trading, then the course that they would develop and teach would have this way of understanding sustainability underlying it. The course may involve case studies and look at the environmental, social and economic trade-offs and decisions that were made in the case study.

Because the education of engineers about sustainability, and specifically for this study sustainable design, is based upon academics' existing understandings of these concepts, students "may experience a limited range of sustainability conceptions, contexts and/or applications" (Carew & Mitchell, 2003, p381). As Crofton (2000) argues, engineering academics are constantly challenged by (i) new advances in science, technology and engineering, (ii) shifting societal demands, (iii) different and changing expectations and priorities for engineering education, revealed by industry, practising engineers, colleagues, and students, and (iv) that the 'half-life' of much of engineers' body of knowledge is about five years and shrinking. As such, academics do not deliver a fixed body of knowledge, but rather one that is constantly changing (Dall'Alba, 1993). Thus, the ways of experiencing the field are constantly changing also "through interaction with others, exposure to new ideas and reflection upon the current way of seeing" (p310). These factors limit the ways academics experience sustainable design, which in turn limit the educational experiences they are capable of delivering.

Further, it is argued that academics in Australia generally lack the range of experiences and understandings of sustainable design in practice to prepare students adequately for professional practice (Mann et al., 2005). “It is harder for academics to gain insight into current practices because design practice requires a much longer periods of *in situ* work than in more technical work” (p4). While, for example, German engineering academics are likely to have between ten and fifteen years industry experience before moving into academia, this is not generally the case for academics in Australia (Board of Manufacturing and Engineering Design, 1995). What this means for the design of engineering education programs and curricula with respect to the practice of sustainable design will be explored in the following chapters.

### *2.4.2 A Critical Review of Traditional Engineering Education*

The main criticism of the traditional approach in engineering education in a formal university setting is that it takes a reductionist approach, separating content, in the form of knowledge, skills and values, from professional practice (Dall'Alba & Sandberg, 1996; Walther & Radcliffe, 2006a). Prevailing theories of professional learning see practice as a ‘container’ for particular forms of social interaction and having an “objective structure consisting of institutionalised social rules and norms” (Dall'Alba & Sandberg, 1996, p413; Lave, 1993). When seen in this way, it is possible to decontextualise content from practice, and study the two independently. The decontextualised content becomes the basis of formal education programs. Further, in current engineering education, the content is not only decontextualised, but fragmented into specific discipline and subject areas. So for instance mechanical engineering students do not learn about the practice of mechanical engineering, but learn fragmented subjects such as mechanics, dynamics, thermodynamics, fluid mechanics and design, without an understanding of how they relate to each other or to practice.

This process of decontextualisation and fragmentation is what Schein (cited in Schön, 1995, p29) refers to as the ‘normative professional curriculum’: first, teach students the relevant basic science, second, teach them the relevant applied science, and third, “give them a practicum in which they can learn to apply classroom knowledge to problems of everyday practice”. The discrepancy between ‘scientific knowledge’ taught in engineering programs and knowledge valued by practitioners is highlighted by Schön

(1983; 1995). He identifies that most knowledge in practice is 'knowledge-in-action' and includes tacit knowledge, skills and attitudes that cannot be separated from each other or the professional action. As Schön (1995, p30) remarks:

> *If a skilled performer tries to teach (and therefore, in part, describe) her knowing-in-action to someone else, she must first discover what she actually does when confronted with a situation of a particular kind. So… a calculus teacher might have to 'see what he does' when he is asked to say how he sets up a problem of differentiation or integration… If we want to discover what someone knows-in-action, we must put ourselves in a position to observe her in action. If we want to teach our 'doing', then we need to observe ourselves in the doing, reflect on what we observe, describe it, and reflect on our description.*

Knowledge, skills, attitudes and values are all vital parts of a professional education such as engineering, and combine in an integrated sense to form engineering skills. These engineering skills are not specific traditional skills, but broader engineering skills such as problem solving or design. Skill development in traditional professional education is seen as the progressive, stepwise accumulation of knowledge, skills, attitudes and values. However "practitioners cannot meaningfully be separated from their activities and the situations in which they practice" (Dall'Alba & Sandberg, 1996, p413). Content and practice cannot be separated and taught independently and still produce the level of skill that is aimed for (Walther & Radcliffe, 2006c).

Further, empirical research (see, for example Billet, 2001) has found that practice varies across contexts, as does what is regarded as skilled performance (Dall'Alba & Sandberg, 2006). Viewing learning as filling up with knowledge fails to address the way in which the learning content is experienced by the learners, identified as critical to learning (Dall'Alba, 1993; Dall'Alba & Sandberg, 1996; Marton et al., 1984; Ramsden, 2003).

### *2.4.3 A Model for Sustainable Design Education*

The goal of engineering education is to develop and broaden students' experiences of the field of engineering, along with the meaning those experiences have for them (Dall'Alba, 1993). These two aspects, experiences and their meaning, must be developed concurrently, as both are necessary for practice as a competent practitioner. For this to happen, engineering programs and courses must provide students with experiences to both develop their level of skill, along with their way of experiencing practice (Dall'Alba, 1993; Dall'Alba & Sandberg, 2006).

It is argued that professional development is not a stepwise process of moving through fixed sequences of stages as normally understood (Dreyfus, 2002; Dreyfus & Dreyfus, 1986), but rather one of continual development. Further, the focus on moving through a fixed sequence of stages takes attention away from developing understanding of, and in, practice (Dall'Alba & Sandberg, 2006). "Understanding is not seen here as limited to cognitive content or activity; rather… [it] is embedded in dynamic, intersubjective practice… [and] integrates knowing, acting, and being" (p388-389). This embodied understanding, what Dall'Alba (2004) describes as an unfolding professional way-of-being, forms the basis of professional development. "Professionals not only learn knowledge and skills, but these are renewed over time while becoming integrated into ways of being the professional in question" (Dall'Alba & Sandberg, 2006, p389).

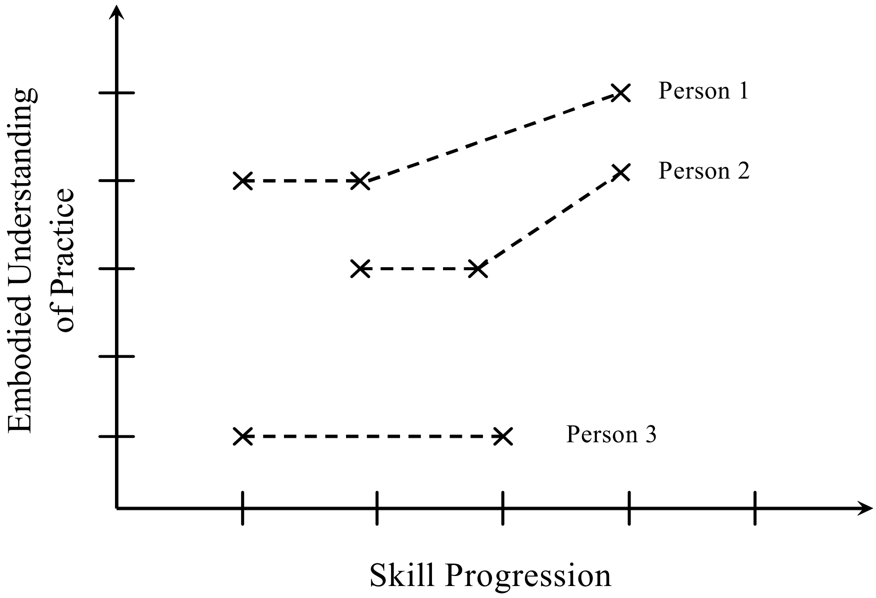


**Figure 2: Model of Professional Development[2]**

The different ways of experiencing practice are central to how practitioners perform in and develop their own practice (Dall'Alba, 2004). This notion of differing ways of experiencing practice, along with skill progression, forms the basis of a new model of professional development (Dall'Alba & Sandberg, 2006). The model is presented diagrammatically in Figure 2, with illustrations of some possible trajectories of development.

[2] Adapted from Dall'Alba & Sandberg, 2006.

The horizontal axis of Figure 2 shows skill progression, such as the use of computer-aided design or engineering problem solving. These skills are the skills that allow an engineer to effectively act in practice. This progression can also be linked to increasing experience with the skill that is being developed (Dall'Alba & Sandberg, 2006). While it does not follow a fixed sequence of steps, points can be identified along this axis similar to the stages Dreyfus (2002) identifies; those of novice, advanced beginner, competent, proficient and expert. These can be used to determine where practitioners are in their skill development for the assessment of professional development. The vertical axis represents qualitatively different ways of experiencing practice. “In any one social, historical, and cultural context, there are likely to be a limited number of qualitatively different ways in which a particular practice is understood and carried out” (Dall'Alba & Sandberg, 2006, p400).

From this model of professional development, learning is seen as moving along both axes in some way within a particular practice context. This could be as: (i) moving from less comprehensive to more comprehensive ways of experiencing aspects of practice (moving vertically), while integrating current skills (x axis) into this new way of experiencing. (ii) Developing more advanced skill levels (moving horizontally), while integrating this into an existing way of experiencing (y axis). For instance, “some professionals may devote most of their working lives to refining an existing understanding, making considerable progress along the horizontal dimension with limited change on the vertical dimension” (Dall'Alba & Sandberg, 2006, p400-401). (iii) A combination of both, developing more advanced skills and more comprehensive ways of experiencing practice (moving diagonally). The model also acts as a way of organising knowledge, skills, attitudes and values within an understanding of practice.

An implication of this model is that if the different ways of experiencing practice are not taken into account in formal education, either at university or in a professional context, then students and practitioners will continue to learn content and skills within their less comprehensive way of experiencing practice (Dall'Alba, 1993). This is discussed further in Chapter 6.

## 2.5 Conclusion

This chapter reviewed some of the current literature on sustainability in general and how it is applied to engineering (Section 2.2). It also discussed some of the current practices of sustainable design, focused around a set of six principles and the holistic thinking process (Section 2.3).

The chapter concluded with a critique of the current state of sustainable design education in engineering. Section 2.4.1 presented some of the current efforts at characterising the development of engineering skill. This was however decontextualised from practice, as discussed in Section 2.4.2, and thus fails to develop students' ways of experiencing practice, identified as the primary goal of professional education. Section 2.4.3 presented an alternative model of professional practice, shown in Figure 2.

If this is to be adopted within engineering education, and specifically within sustainable design education, the ways of experiencing the practice of sustainable design need to be identified. This will also help to inform the practice of sustainable design. The rest of this thesis aims to do this by examining the experiences of sustainable design practitioners, and uncovering the different ways of experiencing practice that exist among them.

# 3 PHENOMENOGRAPHY AS THE RESEARCH APPROACH

## 3.1 Introduction

This thesis is an exploratory investigation of the variation among practitioners' experiences of sustainable design. As such, a qualitative research paradigm is used to explore and describe these variations (Creswell, 1998). This chapter presents an overview of the qualitative research approach used, namely phenomenography (Marton, 1986). This approach carries with it certain ontological and epistemological assumptions and methodological procedures that need to be clarified before a full appreciation of the study can be attained. To this end, the first section of this chapter, 3.2, presents a way of understanding how people experience aspects of the world. An overview of phenomenography is presented in Section 3.3, including a brief history of the development of the research approach, the object of study, and the outcomes from a phenomenographic study. Section 3.4 details the data gathering and analysis processes within phenomenography. Finally in Section 3.5, the issues of validity, reliability and generalisability are discussed.

# 3.2 Experiencing Aspects of the World

> *Perhaps you remember the story in which a group of blind people encounters an elephant for the first time? One approaches the beast from behind, nervously handling the tail. He shouts a warning: the elephant feels like a snake hanging in the air. For the second, encountering a back leg, the experience is very different: she reports she has her arms around a warm tree. And so it goes, with others trying to make sense of the hide, belly, trunk, tusks and other bits of the pachyderm's anatomy. The reports are hugely diverse - and yet all are right, to an extent. All the bits add up to an extraordinary, as-yet-invisible whole.*
>
> *(Dosdat & Kalaydjian, 2005, p4)*

People experience aspects of the world such as sustainable design in different ways. Differences may be due to the context in which the aspect of the world is experienced, such as the time of day or the particular mood of the person, or to the person's particular background, education and previous experiences of the aspect of the world. As a participant in Marton, Fensham and Chaiklin's (1994, p467) study of Nobel Lauriat's experiences of scientific intuition says: "One doesn't see with one's eyes, one sees with the whole fruit of one's previous experience."

The differences are also due to the limited number of elements of an 'aspect of the world' that can be discerned and simultaneously be in a person's awareness at any one time. Just as each of the blind people in the introductory quote only encountered part of the elephant at one time and thus, could not discern it to be indeed an elephant, we are not able to think of an aspect of the world in an infinite way. As Marton and Booth (1997, p101) point out, "if we were capable of total experience of situations and phenomena, a sort of panaesthesia, and if we actually made use of this capability all the time, things would look the same for all time and for all of us".

Instead, we are restricted to experience aspects of the world in particular ways. As we experience an aspect of the world, or more precisely, as we discern and experience variation in an aspect of the world, the more we learn about that aspect. As humans, we participate in an ongoing constitution of the world; we do not construct it afresh nor do we grow into a world that is already constituted (Marton, 1996). As Bowden and Marton (1998, p7) argue:

> *To discern an aspect is to differentiate among the various aspects and focus on the one most relevant to the situation. Without variation there is no discernment. We do not think in a conscious way about breathing until we get a virus or walk into a smoke-filled room. Learning in terms of changes in or widening in our ways of seeing the world can be understood in terms of discernment, simultaneity and variation. Thanks to the variation, we experience and discern critical aspects of the situations or phenomena we have to handle and, to the extent that these critical aspects are focused on simultaneously, a pattern emerges. Thanks to having experienced a varying past we become capable of handling a varying future.*

Thus, as we experience sustainable design in different ways and discern variation within it, our experience of it changes and becomes more comprehensive. It will always be a subset of the 'infinite', ever changing picture, but it will include some of the critical elements of sustainable design as experienced. This way of seeing different parts of an unattainable whole is discussed by Marton and Booth (1997, p106). In particular, they discuss students trying to solve a problem:

> *The variation between the different ways of seeing the problem can thus be understood as a variation in the extent to which the various aspects of a full understanding of the problem are discerned and simultaneously present in the students' focal awareness. Different ways of understanding a problem are thus partial, and whatismore, they are differentially partial.*

The main issue is that our experiences are incomplete. Different people may therefore hold different aspects of a problem or of the world in their awareness at a particular time, and these are products largely of their past experiences. By examining many peoples' experiences, a larger picture of the aspect of the world can be constructed. Hasselgren & Nordieng (2002) remark, "Whatever phenomenon or situation people encounter, we can identify a limited number of qualitatively different and logically interrelated ways in which the phenomenon or the situation is experienced".

These different ways of experiencing an aspect of the world both contribute to understanding the aspect, combining to build a larger picture, and help us to understand how different people have experienced and learnt about the aspect in the past. They are, in effect, a list of experienced variations of the aspect of the world under study (Trigwell, 2000). These experienced variations can be captured into a 'way of experiencing' an aspect of the world for a particular person. Understanding how people have experienced aspects of the world in the past will help to understand how people can approach and handle aspects of the world in the future (Marton & Booth, 1997).

As an example of experiencing an ordinary aspect of the world, Bowden and Marton (1998, p33) discuss trying to hit an object with a ball:

> *While growing up, we keep throwing things of different sizes and different weights such as toys, different kinds of balls, pebbles or pieces of wood. Often we try to hit something, a target, from different directions and different distances. Sometimes it is windy, sometimes it is raining. In this way we learn to discern the relevant aspects of situations that are critical in relation to our objective of hitting something; aspects such as distance, weight, position and possibly even wind strength. When throwing, we try to capture all those different aspects simultaneously. If we fail to capture all critical aspects we probably will not succeed. So the experience of trying to hit a target with a ball can be characterized in terms of what aspects of the situation are discerned and are simultaneously in the focus of awareness, and how they are related to each other.*

To use the analogy of the elephant in a further example, a group of people come to an elephant while on safari. One woman was told stories of elephants as a child, although she had never seen one in reality. The experience of the elephant may cause a certain wonder for her as she remembers the stories from her childhood and looks in amazement at the elephant in real life. Another member of the safari group may have had previous experience riding an elephant on a tour. His experience would then be influenced by this ride, especially if it was particularly good or bad. Another may have been a veterinarian at a zoo and had to care for a sick elephant. When the group meets the elephant on the safari, each will bring a different set of experiences to the new situation.

Similarly, sustainable design has been developed as a different approach to design. There are no absolutes with sustainable design, it is very dependent on the context in which it is applied and who is applying it. Sustainable design may be different in different countries, in different cultures, in different religions and even between different individuals. There will, however, be some critical aspects of individuals' experiences of sustainable design, as there is with all aspects of the world. The key variations of these critical aspects are the focus of this study.

These variations will reveal the qualitatively different ways that people have experienced sustainable design in practice. As each of these is a subset of the 'infinite' way of experiencing sustainable design, it is logical then to assume that these different ways of experiencing may be related to each other. These different ways range from less comprehensive, incorporating fewer facets, to more comprehensive experiences of sustainable design. It is possible to imagine a hierarchy based on this range of different ways of experiencing sustainable design from less comprehensive to more comprehensive.

Different ways of experiencing sustainable design have implications for how to educate others about it. Looking at the different ways aspects of the world have been experienced in the past has been used to explain why different people learn about the same topic in different ways (Marton & Säljö, 1976). One of the aims of education is to help people move from less comprehensive to more comprehensive ways of dealing with aspects of the world. Looking at the different ways of experiencing sustainable design can help people to move from less comprehensive to more comprehensive ways of experiencing sustainable design (Johannson et al., 1985).

## 3.3 Phenomenography: Exploring Variations in Experiences

The research approach developed to elicit and analyse the variations in ways of experiencing aspects of the world is known as phenomenography. This section presents an overview of phenomenography, and explains how it can be used to explore practitioners' experiences of sustainable design. It includes a brief look at the history of the approach, the object of study and the outcomes.

### *3.3.1 History of Phenomenography*

Phenomenography is the empirical study of the qualitatively different ways in which aspects of the world are experienced. That is, it involves mapping phenomena, or the relations between persons and aspects of their world (Marton, 1994). It is a qualitative research approach first used in the original work of the Swedish researchers Ference Marton (1981a; 1981b; 1976), Roger Säljö (1981; 1988), Lennart Svensson (1983) and Lars-Öwe Dahlgren (1984) in the mid-70s.

Phenomenography was initially developed to investigate learning among university students, leading to identifying the 'surface' and 'deep' approaches that are widely known in education circles today (Marton & Säljö, 1976). Phenomenography appeared in its own right as a research approach for describing people's experiences during the early 1980's (see for example Marton (1981a; 1986)). It is important to note that, historically, it was an empirical approach, and only more recently research has been conducted to elaborate the underpinning theory (Marton & Tsui, 2004; Pang, 2003).

Historically, phenomenography has been used to research the experience of learning, the experience of teaching, the different ways of experiencing the content learned, and describing aspects of the world around us (Bowden, 2000). In addition to this, two 'types' of phenomenography have evolved: developmental phenomenography (Bowden & Walsh, 2000) which focuses on the research producing practical outcomes (Green, 2005); and 'pure' phenomenography (Marton, 1986), which aims to describe how people conceive of various aspects of their reality, and where the identification of the variations in the ways of experiencing aspects of the world are a legitimate outcome in their own right (Marton & Booth, 1997). In developmental phenomenography:

> *The research is intended to inform and influence practice (as well as add to a body of knowledge). In other words, research is not conducted merely for its own sake, but rather to inform and improve practice" (Green, 2005, p35)*

The research described in this thesis uses developmental phenomenography, in that it examines sustainable design practitioners' ways of experiencing sustainable design, in order to better inform current practice, as well as to help educate future engineering students about sustainable design.

Since its beginnings, phenomenography has been used in different fields to identify the variations in aspects of the world (Trigwell, 2000). Some of these are presented in Table 3, including Chemistry, Economics, Health Sciences, Higher Education and Music. Of the studies undertaken in the field of engineering identified, all three used phenomenography to improve the education of engineers about a particular field of study (Baillie, 2004; Case, 2000; Davies & Reid, 2001).

**Table 3: Fields of Study Investigated Using Phenomenography[3]**

| Field of Study | Area | Reference |
|---|---|---|
| Biology | Photosynthesis | (Hazel et al., 1996) |
| Chemistry | States of Matter | (Renström et al., 1990) |
| | Mole Concept | (Lybeck et al., 1988) |
| Computing | Learning Technologies | (Cope & Ward, 2000) |
| | Programming | (Booth, 1992; Bruce et al., 2004; Pham et al., 2005) |
| Economics | General | (Dahlgren, 1997) |
| Environment | Education | (Hales & Watkins, 2004; Loughland et al., 2002; Loughland et al., 2003; Petocz et al., 2003) |
| | Volunteering | (Gooch, 2002) |
| Health Sciences | Medicine | (Dall'Alba, 1998; 2002; Stålsby Lundborg et al., 1999) |
| | Nursing | (Kärner et al., 2004; Schröder & Ahlström, 2004; Sjöström & Dalhlgren, 2002; Widäng & Fridlund, 2003) |
| | Physiotherapy | (Abrandt, 1997) |
| Higher Education | Graduate Attributes | (Barrie, 2003; 2005) |
| | Teaching Strategies | (Dall'Alba, 1993; Trigwell et al., 1994) |
| | Academic Development | (Åkerlind, 2003) |
| Management | Competence | (Sandberg, 2000) |
| Marketing | Service Quality | (Schembri & Sandberg, 2002) |
| Mathematics | General | (Crawford et al., 1994) |
| | Statistics | (Reid & Petocz, 2002) |
| Music | Instrumental | (Reid, 1996) |
| Physics | Electricity & Magnetism | (Prosser, 1994; Prosser et al., 1996) |
| | Sound | (Linder & Erickson, 1989) |
| | Mechanics | (Bowden et al., 1992; Jauhiainen et al., 2003) |
| | Education | (Stephanou, 1999) |
| Engineering | Education | (Case, 2000) |
| | Design | (Davies & Reid, 2001) |
| | Materials | (Baillie, 2004) |

[3] Adapted from (Trigwell, 2000)

### 3.3.2 *Object of Study*

The object of research in phenomenography is the variation in the ways of experiencing different aspects of the world (Marton & Booth, 1997). It is about describing the world as experienced, and revealing and describing the variation that exists (Bowden, 2005). Figure 3 illustrates this focus of phenomenography, not on specific aspects of the world, or the subjects themselves, but on the relationships between them.

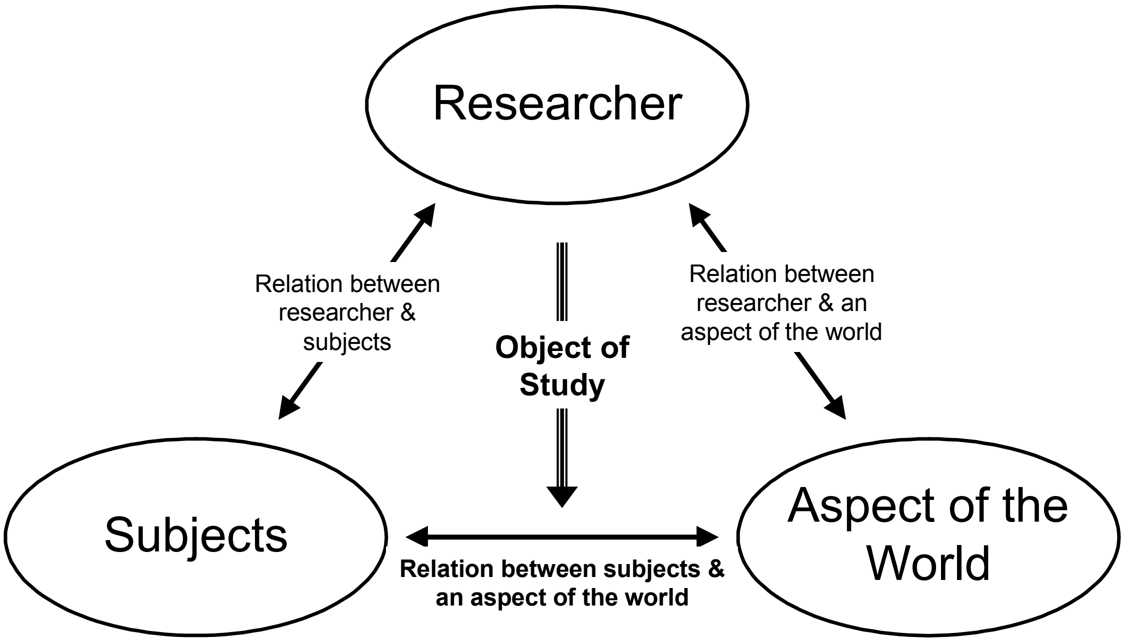


**Figure 3: Focus of Phenomenographic Research**[4]

While certain aspects of the world could be investigated independently of the people experiencing them, as in most positivist research (Silverman, 2001), what is of interest to this research is how people interact with and experience aspects of the world. Hence, phenomenography takes the position that experience is relational, not purely objective, independent of people, nor purely subjective, independent of the world. Knowledge is then created from the relations between persons and in relation to the world. As Marton & Booth explain, with reference to a learner (1997, p 13):

> *There is not a real world 'out there' and a subjective world 'in here'. The world [as experienced] is not constructed by the learner, nor is it imposed upon her; it is constituted as an internal relation between them. There is only one world, but it is a world that we experience.*

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[4] Adapted from (Bowden, 2005), p13

They go on to argue that this applies specifically to describing the world around us, using an analogy of the Big Bang (p113):

> *We cannot describe a world that is independent of our descriptions or of us as describers. We cannot separate out the describer from the description. Our world is a real world, but it is a described world, a world experienced by humans. Quite obviously, humans did not cause the Big Bang, but the way in which it is conceptualized and described is a human way of conceptualizing and describing it. The implication of this is not necessarily that our way of understanding the Big Bang is flawed or distorted, but that it is partial. Furthermore, the human mind can hardly conceive of what it would take to conceive of the Big Bang through means other than the human mind.*

The focus on the world as experienced gives phenomenography a non-dualist ontology. It takes neither a positivist/objective approach, independent of human interpretation, nor does it take a subjectivist approach, focusing on internal constructions by the subject (Marton & Booth, 1997; Trigwell, 2000). We are not interested only in what people think *per se*, but instead what their experiences are and have been in situations where they have had to deal with aspects of the world. What people think may be clouded by rhetoric that they have been told or read, whereas their experiences reveal more about their understandings of the aspect of the world of interest.

A non-dualist ontology also has implications for the relationship between the researcher[5] and the aspect of the world under investigation, as depicted in Figure 3. This relationship is important as it allows the researcher to carry out the research, as some understanding of the research topic is needed to interpret the statements made, and to keep the research focused. However, any preconceptions or theories about the aspect of the world under consideration that the researcher has from their own experiences must be bracketed or held at bay during the research (Sandberg, 1997). This allows the researcher to be open to other ways of experiencing the particular aspect of the world under study, and able to present these other experiences as genuinely as possible.

[5] As this chapter provides a general overview of phenomenography, third person is used to refer to a researcher in general. As such, 'the researcher' is used instead of 'I'. The other chapters that describe the research I conducted use first person.

Trigwell provides an overview of how phenomenography is distinguished from other research approaches (2000, p77):

> *The key aspects of a phenomenographic research approach … are that it takes a relational (or non-dualist) qualitative, second-order perspective, that it aims to describe the key aspects of the variation of the experience of a phenomenon rather than the richness of individual experiences, and that it yields a limited number of internally related, hierarchical categories of description of the variation.*

These aspects and their points of departure from other research approaches can be seen in Figure 4. Phenomenography can be found along the right, with other research approaches deviating at five points of departure: (1) Phenomenography is non-dualist in that reality is seen as constituted from the relations between the individual subjects and an aspect of the world (Trigwell, 2000). (2) It is methodologically qualitative as it tries to explore and describe a phenomenon in terms of the relations between persons and an aspect of the world. The categories of description are also drawn from the data, rather than trying to fit the data to predetermined categories.

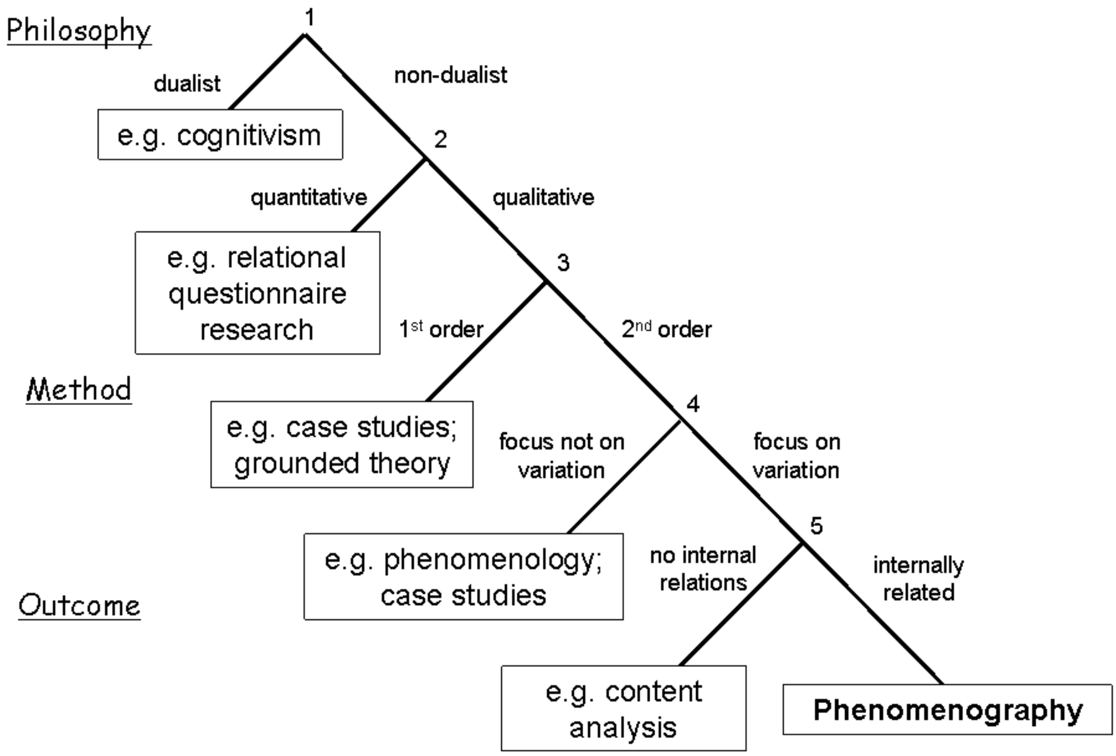


**Figure 4: Points of Departure Between Phenomenography and Other Research Approaches**[6]

[6] Reproduced from (Trigwell, 2000)

(3) Phenomenography takes a second order approach, as it is the experiences of others rather than the researcher, that are the base of the investigation (Trigwell, 2000). (4) It focuses on the variation in the ways an aspect of the world has been experienced. As Trigwell (2000) points out, this is fundamentally different from other research approaches. (5) Finally, phenomenography results in a set of categories that are internally related. The focus on qualitatively describing the variations and relationships *between* categories of description is one of the major differences between phenomenography and other research approaches, such as alternative conceptions research (Bowden et al., 1992).

One of the strengths of phenomenography is that it "provides a way of looking at collective human experience of phenomena *holistically* despite the fact that such phenomena may be perceived differently by different people and under different circumstances" (Åkerlind, 2005a, p72).

### 3.3.3 Outcomes of Phenomenography

The major outcomes of a phenomenographic study are the description and organisation of the variations in 'ways of experiencing' an aspect of the world into 'categories of description', and the organisation of these categories into a hierarchy from less comprehensive to more comprehensive, referred to as an 'outcome space' (Åkerlind, 2002). The categories of description are an attempt to clarify the different ways the same aspect of the world has been experienced by a group of people who are all highly confident that their interpretation is the most reasonable (Åkerlind, 2005a).

The hierarchical relationships between the categories are not value judgements from 'better' to 'worse' (Åkerlind et al., 2005). However some categories of description are inclusive of other categories and, as such, the structural relationships in a phenomenographic outcome space are those of hierarchical inclusiveness. This also leads to the structure not necessarily being linear, but instead may contain forks or branches. However, the categories of description developed can never form an exhaustive system for the aspect of the world, but they should be complete for the experiences of the group of participants under consideration at a particular point in time (Åkerlind, 2002; Marton & Booth, 1997).

The following three criteria for judging the quality of the categories of description developed in a phenomenographic study are put forward by Marton and Booth (1997):

1. The individual categories should each stand in clear relation to the aspect of the world under investigation so that each category tells us something distinct about a particular way of experiencing the aspect of the world;
2. The categories have to stand in a logical relationship with one another, a relationship that is frequently hierarchical;
3. The system should be parsimonious, which is to say that as few categories should be explicated as is feasible and reasonable, for capturing the critical variation in the data.

Marton and Booth (1997, p114) argue that the final categories of description and the outcome space they create is a depiction of variation on a collective level, and as such, "individual voices are not heard. Moreover, it is a stripped description in which the structure and essential meaning of the … [categories] are retained while the specific flavours, the scents, and the colors of the worlds of the individuals have been abandoned". The categories are thus not necessarily ones that any one person in 'real life' would identify with; they are constructions that incorporate key variations of discussions with a specific number of people (Cherry, 2005).

In order to make the outcomes of a phenomenographic investigation clearer, the outcomes of two studies mentioned in Table 3 are described. One example of a phenomenographic study from physics that can be related to engineering is a study that Bowden et al. (1992) conducted involving Year 12 school and first year university students' experiences of displacement, velocity and frames of reference. Specifically, one of the study's questions was (p264):

> *A motorboat with its engines running at a constant rate travels across a river from dock A to dock B in a straight line, as shown in [the figure]. Compare the times taken for this journey when the river is flowing and when it is not. Fully explain your answer.*

After analysing the ways the students solved the problem, five different categories of description were found based upon the students' focus in solving the problem, and are detailed in Table 4 (Bowden et al., 1992, p264). The categories are ranked in descending order, that is, from most comprehensive to least comprehensive. In this way, category Rd, which distinguishes frames of reference, is a more comprehensive way of viewing the problem compared to just looking at a combination of velocities, as for category V, or just distance in category D. Category Rd includes the other categories, as an understanding of distance and velocity is needed to understand relative velocities, but it incorporates them in a different way.

**Table 4: Categories of Description for Displacement, Velocity and Frames of Reference Study**

| Category | Summary of Category | Student Focus |
|---|---|---|
| Rd | Longer distance relative to river, same speed relative to river, therefore longer time | Distance relative to river, distinguishing frames of reference |
| V | Smaller velocity, same distance, therefore longer time | Velocity, combination of velocities |
| Dp | Longer distance, therefore longer time | Distance; path travelled parabolic or discontinuous (speed of boat unaffected by flow of river) |
| D | Same distance, therefore same time | Distance (speed of boat unaffected by flow of river) |
| F | Less pushing force left, therefore longer time | Force, power, etc. (linear relation to speed and distance [same] taken for granted) |

Another example of a phenomenographic study closer to sustainable design was in environmental education, and examined primary and secondary school students' views of the environment (Loughland et al., 2002; Loughland et al., 2003). Six categories of description were identified, the first three experiencing the environment as an object, with the second three experiencing it in a relational way (Loughland et al., 2002). In ascending hierarchical order, the categories of description were:

**Object Focus**

Category 1: The environment is a place.

Category 2: The environment is a place that contains living things.

Category 3: The environment is a place that contains living things and people.

**Relational Focus**

Category 4: The environment does something for people.

Category 5: People are part of the environment and are responsible for it.

Category 6: People and the environment are in a mutually sustaining relationship.

Again the inclusive nature of the categories is relatively clear. Category 4 is more comprehensive than the first three categories, as taking a relational focus includes seeing the relations between objects, in this case a place that contains living things and people. Experiencing Category 6, where people and the environment are in a mutually sustaining relationship includes seeing that the environment does something for people. In this way, categories of description range from less to more comprehensive.

# 3.4 The Phenomenographic Method

This section presents an overview of the phenomenographic method, and specifically, the processes of data collection and data analysis. Phenomenographic studies need to have a coherent method throughout, from the initial planning stages through the collection of the data, to analysis. Most importantly, the research should have a clear purpose, and all efforts should be planned around that purpose (Bowden, 2000).

## *3.4.1 Data Collection*

The research subjects are identified in the planning stage of the research due to their relationship with the specific aspect of the world under consideration. They should also be selected to obtain as much variation in their experiences as possible, but still within the purpose of the study. To illustrate this need to stay within the purpose of the study, there is no use in wanting to study practising sustainable designers' experiences of sustainable design, with the focus on improving both practice and teaching, and subsequently including community representatives as interviewees. They may help to generate a greater variation in experiences with sustainable design, but the community representatives are outside the purpose of that specific study.

Phenomenographic data collection usually revolves around interviews (Green, 2005). The interviews have an open ended format, with interviewees responding to an initial question or problem. "The researcher and researched must begin with some kind of (superficially) shared topic, verbalised in terms which they both recognise as meaningful" (Ashworth & Lucas, 2000, p299). There are three common types of approaches to conducting phenomenographic research: (i) posing a specific problem in the field of study under consideration, (ii) asking the interviewees to describe concrete situations that have involved an aspect of the world; and (iii) asking 'What is X?' (Bowden, 2000).

In the first and second types, the questions allow the interviewee to pursue facets they deem relevant. The facets they choose and how they approach the question is of interest in the analysis, because these can help to separate the varying ways of experiencing the aspect of the world within the given context of the question or problem (Bowden, 2000). Questions of the form 'What is X?' tend to guide the interviewees either too narrowly or too broadly in the interview, and carry the risk that interviewees may rely on what they think they should say or have heard, rather than what they have experienced. As Bowden (2005, p17) notes:

> *When 'what is X?' questions are asked in such phenomenographic interviews, the outcomes tend to be less varied and they more or less reflect the standard, espoused theories available in the literature. On the other hand, when people are asked to describe their own direct experiences, their immersion in that detail often reveals a much greater variation across the interviews in ways of seeing than with the more narrowing 'what is X?' approach.*

The purpose of the phenomenographic interviews is to reveal interviewees' experiences with the aspect of the world under consideration. As such, interviewees are encouraged throughout the interview to reflect on and reveal their way of experiencing the aspect of the world in context. What is important is what the interviewees think these experiences reveal about the aspect of the world itself, and follow up questions in the interview should focus on eliciting this meaning (Åkerlind, 2005a). As Marton (1994, p4427) argues:

> *The interview has to be carried out as a dialogue, it should facilitate the thematisation of aspects of the subject's experience not previously thematised. The experiences… are jointly constituted by interviewer and interviewee.*

Once the initial question or problem has been proposed, follow up questions ask interviewees to elaborate on their experiences and what they mean by certain concepts. All follow up questions are extracted from what the interviewee has said so far in the interview, and not formed through predetermined ideas and questions from the interviewer. As such, different interviews "may follow somewhat different courses" (Marton, 1986, p42). In this way, the interview is a dialogue or conversation, encouraging the interviewees to reflect on their experiences of the aspect of the world. Judgemental comments from the interviewer should never be made in the interview (Bowden, 2005).

In general, follow up questions take three forms (Green, 2005): (i) seeking clarification; (ii) playing naïve; and (iii) exploring contradictions. In seeking clarification, questions include 'tell me more about…' and 'what sorts of things did that include…?' These are used to obtain a more comprehensive picture of how the subjects have experienced the aspect of the world. In playing naïve, the interviewer uses questions such as 'what do you mean by…' and 'can you explain what … is?' These questions seek an explanation of common concepts or terms that subjects use. Again, the aim is to develop a clearer picture of the way subjects have experienced the aspect of the world under consideration. Finally, exploring contradictions includes constructs such as: 'You talked about X before, but you are now talking about Y. These seem to contradict each other. Can you tell me about that?' These questions not only try to get a clearer picture of the subjects' experiences, but also check the researcher's understandings of those experiences. They may also stimulate reflection, encouraging subjects to think about facets of the aspect of the world that they may not have thought about before.

An important aspect of the phenomenographic interview is the use of empathy to further engage with subjects' life-worlds (Ashworth & Lucas, 2000). As the categories of description are derived from subjects' experiences relayed in the interview, it is "a paramount requirement for phenomenography to be sensitive to the individuality of conceptions of the world" (Ashworth & Lucas, 2000, p297). This is achieved through the process of 'bracketing' the interviewer's own assumptions and theories, and instead being empathetic to the subjects' experiences of the aspect of the world under consideration. Three of the presuppositions that need to be bracketed which have been identified by Ashworth & Lucas (2000) are: (i) importing earlier research findings; (ii) assuming pre-given theoretical structures or particular interpretations; and (iii) imposing the investigator's personal knowledge and belief.

In order to help bracket these presuppositions during the interview, the interviewer needs to achieve a level of empathy with the experiences of the subjects being interviewed. While interviewers can't detach themselves from their own life-world, they do need to bracket their own theories and preconceptions, and focus on the experiences of the participant. Ashworth & Lucas (2000, p299 their emphasis) use the following to illustrate this:

> *For instance, views and factual claims which the student expresses in an interview may well be regarded by the researcher as quite erroneous. The temptation would be to marginalise such material. But the researcher who adopts an attitude of empathy with the student should find such views and factual claims of immense interest.*

Another important aspect of the data collection process is conducting pilot interviews to enhance phenomenographic interviewing skills (Bowden, 2005), and to test if the initial questions reveal the sorts of experiences (data) necessary to address the focus of the research (Green, 2005). It is important that the pilot interviews are with people within the target group to obtain practice investigating the sorts of experiences that could be encountered in the final study. It is also important that they are discarded and not included in the final study (Bowden, 2005), as the interviews may contain potential errors that might invalidate the results. Also, it is often the case that the follow-up prompts are more useful in eliciting meaning than the initial planned questions (Åkerlind, 2005a). As these follow-up questions have to be devised 'on the fly' based upon what the subjects say in the interviews, it is vital to practise identifying and asking this type of question during the pilot interviews.

### *3.4.2 Data Analysis*

There is great variation in the methods used to analyse data in phenomenography. The overview presented in this section includes some of the customary procedures in phenomenography, identifies a few key ongoing debates, and forms the basis of the approach used in this study. For a more detailed description of the commonalities and variations in the phenomenographic method of data analysis, see Åkerlind (2002; 2005b).

Interviews transcribed *verbatim* become the focus of the phenomenographic analysis when interviews have been used as the primary means of data collection. The set of transcripts represent a 'snapshot' of some of the experiences of a group of people with a particular aspect of the world in response to a particular set of questions at a particular time (Åkerlind et al., 2005). When data collection has relied only on interviews, no other evidence exists beyond the transcripts to inform the analysis process (Bowden, 2005).

The analysis process is both one of 'discovery' (Hasselgren & Beach, 1997) as well as one of 'construction' (Bruce, 2002). The results are not known in advance and tested in the study, but must be discovered, or emerge from transcripts, and constructed in an iterative way from the transcripts. In this way, phenomenographic analysis is a 'bottom up', inductive way of working from the data to the results, rather than a 'top down' way of constructing then testing an hypothesis (Green, 2005). Walsh (2000) criticises taking only one approach, as discovery bypasses the analytical process and construction imposes a logical process, neither of which are easily justified. Bruce (2000) argues that phenomenography involves both approaches occurring simultaneously.

It is important to keep an open mind during the analysis (Åkerlind, 2002). The categories of description may change several times during the analysis process, and the researcher cannot close off to already determined categories. To achieve this, a constant focus must be maintained on the transcripts as the only source of evidence and with constant checking and rechecking of them with the categories. The researcher needs to focus on the transcriptions and categories as a whole set, rather than on individual transcripts or categories in isolation (Green, 2005). Also, the researchers' own presuppositions about the phenomenon must be set aside or bracketed (Ashworth & Lucas, 2000). The researcher must be open to the fact that different people may see the same phenomenon in different ways, which is an epistemological underpinning of phenomenography, but is counter-intuitive to our natural attitude (Bowden, 2005; Marton & Booth, 1997).

Of primary interest in the analysis process are the relationships between the subjects and the aspect of the world under investigation, not the relationship between the researcher and that aspect, as can be seen in Figure 3. Again, constant reference back to the transcripts is critical; if it is not in the transcripts, then it cannot be claimed as a result of the study. Sandberg (1997) acknowledges however that the final categories of description are constructs of the researcher, in collaboration with the subjects, and as such are never completely removed from him or her.

There is an ongoing debate within the field at the moment as to the role the relationships between the categories of description play. Some phenomenographers emphasise not analysing the structural relationships between the categories until the categories themselves are finalised, as it may introduce the researcher's relationship with the phenomenon into the categories (Ashworth & Lucas, 2000; Bowden, 2005). This leads to certain transcripts not necessarily helping to form the categories if they don't seem to fit.

Others argue that focusing on the structure of the categories and outcome space too late could lead to the meaning and structure not being adequately co-constituted in the final outcome space (Åkerlind, 2005a). Åkerlind argues that a strong emphasis on looking for structure in the phenomenographic analysis process is vital, as the focus on structure:

- is an epistemological underpinning of phenomenography;
- increases the potential for practical applications from the research;
- provides a simultaneous focus on variation and commonality.

As the relationships between the categories are developed at the same time, the categories are developed such that each transcript must be included. This thesis specifically looked for the relationships between the categories as the categories themselves were being developed, as discussed in Section 4.6.

The analysis process involves identifying meaning or variation in meaning across the set of transcripts. As it focuses on describing qualitative similarities and differences across the transcripts, phenomenographic outcomes do not show the richness of the data, only variation *for which there is clear evidence from the transcripts* (Bowden, 2005). This focus on facets that are critical in distinguishing the variation between categories of description allows the structural relationships to be highlighted to a degree that would not be possible if "the analysis focused on every nuance of meaning" (Åkerlind, 2005a, p72).

The analysis process starts by the researcher reading and re-reading all the transcripts as a full set of data (Green, 2005). There is an ongoing debate about whether to identify specific statements from the transcripts and analyse them separately, as in the 'pools of meaning' approach (Marton, 1986), or to identify specific statements but always use them in the context of the whole transcript (the 'whole of transcript' approach). This thesis used the latter, where the whole transcript was used to provide context to statements made.

The researcher then tries to articulate the aspect of the world for that transcript. Transcripts with similar individual meanings are then grouped, with the similarities within and differences between the groups clarified. A description of each category is written with illustrative quotations from the transcripts. These descriptions form the preliminary categories for the set of transcripts. It needs to be understood that this first attempt will not necessarily be 'right' and will most likely change. It will, however, provide a different way to see the data, to then revisit and further develop the categories (Green, 2005).

From the initial groups, the researcher identifies transcripts that do not seem to fit into any category, as such transcripts often show a different facet that needs to be considered. The descriptions of the categories are clarified with constant reference back to transcripts as wholes. During this process, the researcher must constantly be asking, 'Is there another way of interpreting this statement?' It is also important to constantly refer to the initial focus of the study, as it is easy to become distracted by particular aspects of the transcripts (Bowden, 2005).

In writing the descriptions of the categories, researchers can only rely on what is included in the transcripts, and cannot extend or speculate on this. The researcher can accomplish this by constantly asking, 'Where in the transcripts does this come from?' almost becoming their own devil's advocate. The final descriptions of the categories should be self-contained, in that they are able to be understood as a set of separate, stand alone statements.

At the end of the analysis process, all of the transcripts are sorted into individual categories of description. The categories themselves should have clearly defined statements of what they are, backed up with illustrative quotations from the transcripts. Pictorial representations may also help to explain the categories. A label for each category of description can also be developed, but this labelling should be avoided until late in analysis, as it may limit further category development (Bowden, 2005).

The relationships between the categories of description should also be detailed, using illustrative quotations where appropriate. These relationships should specify the similarities and differences between the categories and help to reveal categories that are more comprehensive than others. The categories are then sorted into a hierarchy based on their increasing comprehensiveness. This hierarchical representation of the categories of description is known as an outcome space (Åkerlind et al., 2005).

# 3.5 Validity, Reliability and Generalisability

The established concepts of validity and reliability in quantitative research have been adapted to be used for phenomenography, as phenomenography has different ontological and epistemological assumptions than other quantitative modes of inquiry.

## *3.5.1 Validity*

As phenomenography has an underlying non-dualist ontology, questions of validity cannot focus on how well the results correspond to an external 'objective' reality (Åkerlind, 2002). Instead they are focused on the relation between the aspect of the world and those experiencing it (Uljens, 1996).

One aspect of validity in phenomenography is communicative validity. Sandberg (1994, p62-63), claims that "Establishing communicative validity involves an ongoing dialogue in which conflicting knowledge claims are debated throughout the research process". He states there are three phases in the phenomenographic research process where this is relevant: (i) within the interviews communicating with the participants; (ii) in the analysis process communicating with the text; and (ii) in communicating the results to other researchers and professionals.

In the first phase, the development of valid knowledge "presupposes an understanding between researcher and research participants about what they are doing" (Sandberg, 2005, p54). Within this phase the focus is on establishing a dialogue with the participant, rather than the interviewer simply posing questions and the participant responding.

In the second phase during the analysis process, communicative validity "can be achieved by striving for coherent interpretations" (Sandberg, 2005, p55). Coherent interpretation tries to understand the parts in relation to the whole and vice versa. This is accomplished in the analysis by considering phrases within individual transcripts in relation to the whole transcript. Also, grouping similar transcripts and comparing them within and between the subsequent groups further refines the coherence of the final categories of description.

The third phase of establishing communicative validity involves obtaining feedback from other researchers and professionals practising in the area under study. Sandberg (2005, p55-56) argues: "Although single researchers may be the main producers of knowledge claims, it is ultimately intersubjective judgement that determines whether the original researcher's knowledge claim is true [and valid]".

Another aspect of validity applicable to phenomenography is pragmatic validity (Åkerlind, 2002), which concerns the extent to which the outcomes are seen as useful *in practice* (Kvale, 1996; Sandberg, 1994), as well as how meaningful they are to the target audience of the study (Uljens, 1996). The research outcomes are judged by the extent to which they inform more effective ways of dealing with the aspect of the world in practice (Entwistle, 1997; Marton, 1996; Marton & Booth, 1997). Pragmatic validity usually involves using the results to change practice, and evaluating how the changes have or have not improved practice. For example, pragmatic validity applied to an investigation of sustainable design practitioners' experiences of sustainable design, would entail a change in the current practice of sustainable design, based upon the outcomes of the investigation, and seeing if the result improved practice in some way.

One aspect of validity that is not necessary in phenomenography is the need to go back and check the outcomes with subjects, specifically asking them if they agree with their allocation to a specific category of description (Bowden, 2005). The categories of description are developed from the set of transcripts as a whole, not from individual transcripts. So, while each transcript is ultimately assigned to a specific category, the categories are developed together and they may have been developed as much from the differences between categories as the similarities within the category. Also, by going back and checking the outcomes with the subjects, "… you are introducing new material and you might expect any interviewee now to see the phenomenon differently. Learning will have taken place [and]… the interviewee's comments are no longer in relation to just the original common scenario; they are related to the new input" (Bowden, 2005, p30). Communicative validity, however, can involve going back to the original subjects and asking them to comment on the set of categories of description as a whole.

### *3.5.2 Reliability*

Reliability in phenomenography is replaced with the notion of interpretative awareness (Sandberg, 1997; 2005), as the outcomes of a phenomenographic study are interpretive and are thus not necessarily repeatable (the basis of traditional reliability). The characterisation of the qualitative variations between people's experiences of an aspect of the world cannot be based on an *a priori* analysis, but must instead be empirically based (Marton & Booth, 1997). Which variations are critically significant in a particular study will vary between the people whose experiences are the focus, as well as the actual researchers conducting the study. As Cope (2002, p2) points out, "If individuals experience phenomena in the world in different ways, why shouldn't different researchers investigating the phenomenon of variation in a group of individuals' experiences, experience the variation in different ways?". The variations identified in the analysis process are in part judgements made by the researcher as to which are the critical variations, and which are less or more comprehensive ways of experiencing aspects of the world. While these judgements cannot be empirically based, they can be argued (Marton & Booth, 1997).

Interpretative awareness (Sandberg, 1997; 2005) revolves around researchers demonstrating how they have controlled and checked their interpretations throughout the entirety of the phenomenographic research process. This includes the formulation of the research question, the selection of the subjects, interviewing those subjects, phenomenographically analysing the resultant transcripts, and reporting the final categories of description (Sandberg, 1997). In practice, one aspect of this is for the researcher to "acknowledge and explicitly deal with … subjectivity throughout the research process instead of overlooking it" (Sandberg, 1997, p209).

To address this, Green (2005) proposes the idea of rigour of a phenomenographic study. This was used throughout the present study, and involves:

- Preparation for interviewing;
- Open-ended but focused interviewing technique;
- Strategies to avoid as much as possible unplanned researcher impact during interviewing;
- Strategies for consistency among interviews;
- Strict adherence to data;
- Admitting to inconsistencies within transcripts rather than trying to constrain data to appear consistent, i.e. refraining from 'squeezing' people into categories;
- Constantly going back to the data and reading the context of statements;
- Re-reading of the data as a whole;
- The iterative development of the categories;
- Devil's advocacy in developing categories; is there another way of viewing this?
- Presentation of the results, in terms of categories of description and outcome space, discussion of relationships between categories, and illustrative quotes from the data.

Traditionally in phenomenography, interjudge reliability has been used to answer questions of reliability (Johannson et al., 1985; Marton, 1986; Säljö, 1988). It is a form of replicability in that it describes the extent to which other researchers are able to recognise the categories of description identified by the original researcher. Typically, this involves other researchers reading the categories of description developed and trying to categorise the various transcripts into those identified categories; the higher the match with the original researcher's categorisation of transcripts, the higher the interjudge reliability.

The main criticism of interjudge reliability is that it overlooks the initial researcher's procedures in conducting the phenomenographic investigation and analysing the data (Sandberg, 1997). Such procedures may involve poor data collection procedures in interviewing subjects about their experiences, including not properly bracketing the researcher's own understandings. So while other researchers may agree with the categorisation of the transcriptions, the categories themselves may be flawed. Interjudge reliability is also derived from an objectivistic epistemology, as it assumes that there is a set of objective categories out there, removed from the original researcher, which other researchers should be able to identify. Phenomenography however has an underlying relational epistemology, in which knowledge is relational. Due to this inconsistency, Sandberg (1997) argues, reliability is not established using interjudge reliability.

### *3.5.3 Generalisability*

A conventional notion of generalisability is not applicable to phenomenographic research, it examines the variations of the experiences of an aspect of the world for a specific group of people. The group of people are chosen from a population to maximise the variation of experiences, rather than trying to be representative of the population (Åkerlind, 2002). A different sample group in a different context may provide different categories of description, just as different researchers may develop different categories from the same data. As Åkerlind (2002, p12) notes:

> *Consequently, phenomenographic research outcomes have been described as not enabling generalisation from the sample group to the population represented by the group, because the sample is not representative of the population in the usual sense of the term.*

It is expected however that the *range* of variation in the sample reflects the range of variation in the population (Francis, 1996; Marton & Booth, 1997). As such, the results of a phenomenographic study are generalisable to a group with similar characteristics and experiences to the sample group. Further, the range of variation should still be relevant to groups with less in common with the sample group, though it is likely to be a less complete representation of the range of experiences in the larger group. While the range of variation may be generalisable, the distribution of people among the different categories may not be (Åkerlind, 2002). As such, it is important in any phenomenographic study to specify the characteristics of the subjects included in the study so that readers are able to make up their own minds about the generalisability to the group in which they are interested (Cope, 2002).

# 3.6 Conclusion

This chapter presented an overview of phenomenography, including the object of study, the outcomes and some specific aspects of the data collection and analysis processes. The next chapter details how this was translated into practice for this study, describing how phenomenography was used to investigate variations in the experiences of sustainable design practitioners.

# 4 DESIGN OF THE PHENOMENOGRAPHIC INVESTIGATION

*The reality of the research, however, is not a neat sequence from developing an articulated view of the phenomenon to be studied to drawing the methodological conclusions from that view. Rather, by studying the phenomenon, our view of it may change somewhat, which then may lead to some alterations in the research methods adopted, which again may make some new aspects of the object of research visible, which may in turn have a number of implications concerning methodology, and so on.*

*(Johannson et al., 1985, p.235)*

## 4.1 Introduction

This chapter details the design and development of the phenomenographic investigation at the core of this thesis. It builds on the material presented in Chapter 3 regarding the research approach of phenomenography and its use in this thesis. The chapter begins with the development of the context for the thesis, namely the move from a focus on the stakeholders involved with sustainable design, to sustainable design practitioners (Section 4.2). This is presented to articulate the reasons why the final thesis focused on sustainable design, as well as to present a number of the decisions made along the way that shaped the thesis as a whole. Section 4.3 presents a pilot study conducted in 2004 in the form of a workshop, which was used to answer a number of initial questions about sustainable design and to guide the rest of the thesis work. The planning for the main study is then introduced in Section 4.4, including a description of the twenty-two people who were interviewed, the indicators used to ensure diversity among them, and the methods employed in their selection. Section 4.5 covers the data collection process undertaken. This took the form of semi-structured interviews with each of the twenty-two subjects. The interview process and the protocol used during the interviews are presented and discussed. The phenomenographic analysis of the transcripts is discussed next in Section 4.6, with Section 4.7 presenting the efforts made to ensure the validity and reliability of the results. The ethical considerations of this thesis are presented in Section 4.8, including in particular the informed consent and confidentiality of the subjects.

## 4.2 Context Development

The design of the study developed incrementally, with the focus and consequently the research approach changing over the course of the thesis. This evolution occurred for a number of reasons. The first was a shift in my awareness of the problem itself; from, 'What is the essence of sustainable design?' to 'What are the various ways people have experienced sustainable design?' The second shift, which paralleled that of the first, resulted from an increasing awareness of the types of questions that different research approaches were able to answer about the nature of sustainable design. This shift was from looking at what needed to be taught about sustainable design to include how also. The third shift revolved around the change in subjects, from the stakeholders affected by sustainable design, to 'sustainable design practitioners', who deal with sustainable design issues on a daily basis.

Initially, the study focused on sustainability, sustainable design and sustainable development. However, the scope was refined early on to simply sustainable design. This path was pursued for various reasons. As I read more and investigated these phenomena further, key differences among them emerged. Sustainability was seen as the end goal, a goal perhaps that we will never reach. Sustainable development was then anything that progressed society toward that goal. This not only included 'engineering' work, but such diverse topics as women's rights (social sustainability), dry land salinity (environmental sustainability) and free trade (economic sustainability). Sustainable design however is more tangible, and more the realm where engineers can make a significant difference. Sustainable design was about change, change by creating something that replaces an existing way of operating. This could include creating something new, such as a new piece of technology for using energy more efficiently, or changing the way an existing process is conducted, be it physical, managerial and so on. This focus on sustainable design, I thought, could also produce a list of 'things to do in order to design sustainably' to teach engineers. While the final study did not pursue this path, it did focus the study on looking at practical applications of the research outcomes.

As noted in Chapter 1, one of the main motivations for this study was to address the apparent gap in the education of all engineers about sustainable design. While Engineers Australia's Graduate Attributes call for engineering graduates to have "an understanding of the principles of sustainable design and development" (Engineers Australia, 2005, p7), anecdotal evidence and a look at engineering program websites across Australia at the time showed very few engineering programs focused on these topics in some of their courses. One reason cited by Carew & Mitchell (2003) for this is a lack of understanding held by academics about these concepts.

As I investigated sustainable design within engineering further, through further literature reviews and personal communication with various academics across Australia, I found that those claiming to be doing or to be affected by 'sustainable design' had their own, quite disparate views of what it was and how it applied to their own particular situation or discipline. It is important to note that, while these views were different, they were all 'correct' to the persons holding them. There was no one right way. Each person had different experiences from their particular background that engendered a different way of approaching sustainable design. Given that there was no common understanding that encapsulated sustainable design, the question arose as to what to teach engineering students. This appeared to be an interesting and worthwhile problem to investigate.

The first approach to this problem was to identify and examine the various stakeholders affected by sustainable design and to consider their experiences. These were people or groups of people who either had to make sustainable design decisions regularly, or who were affected by the decisions others had made. The common theme among stakeholders was that they were all linked to engineering operations. Because, at the end of this thesis, recommendations would be made about the education of future engineers about sustainable design, engineering operations needed to be core.

While this stakeholder identification process was initially small, it soon became apparent that there were too many stakeholder groups to realistically cope with within the scope of this study (see Appendix B). Also, each stakeholder group did not necessarily have rich enough experiences to contribute in a significant way to discovering the essence of sustainable design. Some other way of answering the research questions was required.

As I investigated more peoples' experiences of sustainable design, more differences than similarities were unearthed. While there were some underlying concepts that were common, such as reducing waste and materials used and so on, even within these, different people applied them differently. In engineering, students are taught that there is a right answer to any problem, that there is an objective world. For example, the second law of thermodynamics does not change when it is applied to an engine versus a chemical process plant, or in Australia or India. Sustainable design appeared to be an engineering topic that was not black and white; instead it appeared to elicit subjective responses in engineers.

Initial investigation suggested that the research approach known as phenomenography offered a way to investigate variations in the ways human beings experience aspects of their world, and specifically how engineers "experience" sustainable design. While the theory behind this research approach was presented in more detail in Chapter 3, it is important to place the selection of the research approach in context. Phenomenography offered a way to reveal critical variations between the ways people had experienced sustainable design, looking at the similarities and differences between them. The approach analyses experiences, because the way people have experienced an aspect of the world in the past informs the way they will deal with it in the future.

Phenomenography typically involves interviewing people and asking them about their experiences with a particular aspect of the world. Through these interviews, a model of the variations in the ways that sustainable design had been experienced could be developed. The richer the experiences that can be related in the interview, the richer the model that could be developed would be.

This need for rich descriptions of experiences meant that a focused selection of stakeholders was required. The focus needed to be on people who had to deal with sustainable design issues on a daily basis, not simply anyone affected by it. These people were termed 'sustainable design practitioners' and were people who actively practised sustainable design and who had developed their own understanding of what sustainable design meant for them through personal experience (Mann et al., 2005).

A phenomenographic approach also broadened the research focus from *what* to teach engineers about sustainable design, to also include a question of *how*. The results from a phenomenographic investigation are a set of categories, as discussed in Section 3.3.3, which represent qualitatively different ways that sustainable design has been experienced by the sustainable design practitioners interviewed. The categories could be used to investigate how to teach engineers about sustainable design, including pedagogical practices and the process of learning about sustainable design. They could be used to determine what to teach also.

The final consideration was about the interviewees themselves. Since the focus was on experiences of sustainable design in engineering operations, it was logical to interview engineers. The current practice of engineering, however, does not necessarily have sustainable best practice at its heart. What engineers should know to be able to practise sustainably in the future was the focus of the study. This led to the inclusion of both engineers and non-engineers in the research, as some non-engineering groups have had a longer history of dealing with sustainable design issues. A criterion for selection, however, was that these non-engineers had experienced engineering operations.

# 4.3 Stakeholders' Experiences – The Pilot Study

The following questions were initially proposed for this thesis:

1. What are the stakeholder groups' experiences of sustainable design?
2. What are the similarities and differences between these experiences?

While the focus of the study evolved to examine 'sustainable design practitioners' for the final set of interviews, who these practitioners were, the reasons for the shift, and indeed the scope of the entire thesis grew from the initial work conducted on identifying stakeholder groups. A pilot study was conducted to identify different stakeholder groups, and centred on a workshop aimed at identifying people to interview in the next stage of the study, as well as validating an influence model for the stakeholder groups that had been developed. The model, as well as the workshop and subsequent findings and analysis, are presented in this section.

In order to gain the maximum diversity of experiences, the main stakeholder groups were characterised and analysed. The underlying assumption was that each stakeholder had an equally valid view of what sustainable design meant within their context and from their experience. The first set of stakeholder groups was developed through reviewing the literature and discussions with colleagues, and initially comprised the following stakeholder groups:

- Australian Industry
    - As private companies, both small to medium enterprises (SME), national and multi-national companies from an Australian perspective;
    - As peak industry bodies, both national and international ;
- Governments at all levels
    - As employers of engineers ;
    - As regulators of engineering practices, activities and registration;
- Engineering Institutions and the Engineering Profession, specifically
    - As professional institutions in Australia;
    - As accreditors of universities' engineering programs in Australia;
- Australian Universities, specifically
    - As an entity (senior management);
    - As a collection of academics;
    - As an educator of students;

- The Community
    - As non-government organisations (NGOs);
    - As lobby groups that drive regulation;
    - As the local community impacted by engineering projects
    - As consumers of technology and other products of engineering.

A model of the interaction between these stakeholder groups was developed to further investigate the groups themselves, and the influences they had on each other. The influence model is illustrated in Figure 5, and helped to elicit a greater understanding of how these stakeholders experienced sustainable design, and thus who to target in the interview phase. The model describes the influences each stakeholder group has on other groups and run both ways.

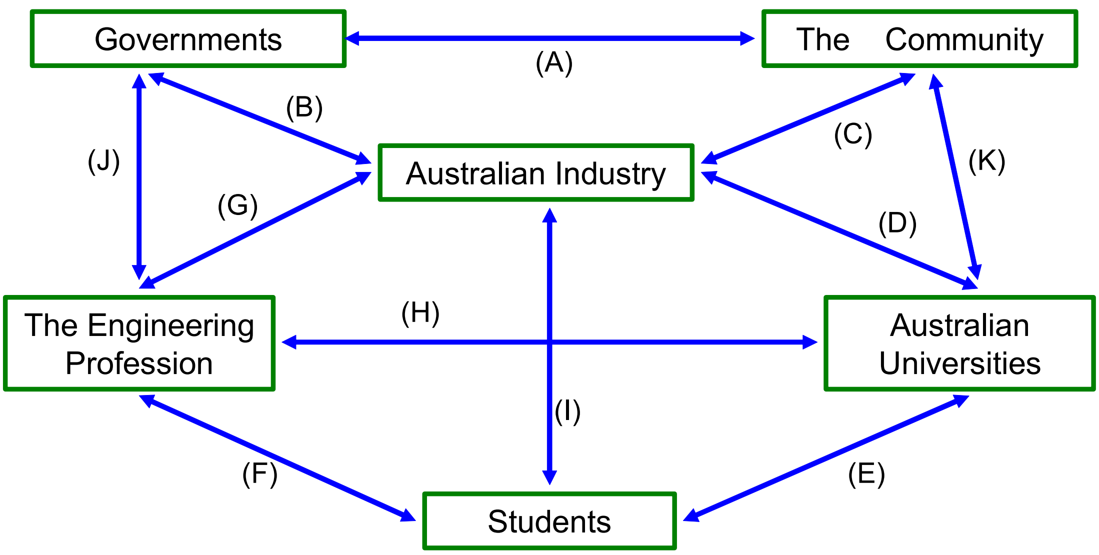


**Figure 5: Initial Stakeholder Influence Model**

From Figure 5, (A) the community drives government interest and focus on sustainable design. The government either follows community opinion or takes the lead in focusing on sustainability issues. In turn, the government influences the community through policies and activities it undertakes around sustainability issues. (B) Governments legalise the operations of Australian industry around sustainable design, and in turn Australian industry has an influence on the policies and the activities undertaken by governments. (C) The community builds an image of Australian industry from its perceptions of industries' approach to sustainable design issues. In turn, Australian industry influences the ways that the community lives and works, as they are the providers of many of the products and services that the community uses. The community also builds an image of Australian universities, while universities draw support from the community (K).

Australian industry also influences the approach taken by Australian universities to sustainable design (D). Calls from industry to educate students about sustainable design will influence the engineering programs universities offer. This will potentially attract more students with higher job prospects at the end of their degree (E). These students will then join the engineering profession (F) who will in turn support them as members. Students will also find a career in Australian industry (I). The engineering profession acts as a representative of engineers in Australian industry (G) and also accredits and influences the engineering programs offered by universities (H). The engineering profession also influences government policy and decisions, and in turn is regulated by government (J).

This model was developed to gain a better understanding of the stakeholders in the education of engineers about sustainable design. It was also used to identify groups from which subjects for the interview phase of the study could be chosen.

### *4.3.1 Overview of the Workshop*

The pilot study workshop was delivered at the Australasian Association for Engineering Education (AaeE) annual conference held in Toowoomba in 2004. Seventeen academics from across Australia and New Zealand participated in the workshop run over a period of an hour and a half. At the time of the workshop, the study was still focused on sustainability, sustainable design and sustainable development. The workshop was carried out: a) to verify the influence model, b) to gain some general scoping data about what people thought sustainability was, c) to find out what engineering students should know about sustainability, and d) to provide some examples of 'best practice' in teaching sustainability around Australia. The workshop was run as an interactive exchange, divided into three sessions. After a brief introduction, the subjects were presented with a series of three questions about sustainability, sustainable design and sustainable development:

1. What is it?
    - A concept map of sustainability, sustainable design and sustainable development;
2. Who cares?
    - A map of stakeholder groups, links between them and why they are a stakeholder;
3. What do students need to know?
    - A list of attributes students needed to learn. What are your experiences teaching sustainability? Who in Australia to look at for 'best practice'?

The workshop aimed to produce three concept maps: what is sustainability, the stakeholders involved in sustainability, and what students needed to know about sustainability. A list of examples of 'best practice' was also developed. It should be noted that the pilot study was more focused on verifying and developing the set of stakeholders already identified to help with the selection of interviewees, rather than collecting primary data for the study. Hence, while the data obtained in the other two areas were of interest and added to the development and focusing of the study, they were not analysed exhaustively, or with any particular approach in mind. This is discussed further in Section 4.3.3.

The subjects were asked in groups of four to five to develop concept maps of the three topics using a sheet of card and sticky notes provided. Four groups were formed: 'Clueless', 'Future Facilitators', 'Parhelion' and 'Phoenix'. After each session, the groups' concept maps were posted around the room for everyone to consider and discuss. These maps formed the base data in the pilot study and can be seen in Appendix A. Note that not only what was written was captured, but who wrote what within each group (represented by different coloured writing in the boxes) and the location of the boxes.

The focus of the workshop was verifying the stakeholder model. After the second session, which involved the groups developing their own stakeholder group concept maps, they were presented with the developed stakeholder influence model and asked to comment. Subsequent discussion led to a refinement of the model, as presented in Section 4.3.3.

### *4.3.2 Workshop Findings*

The three sets of transcribed concept maps were analysed by examining similarities and differences between the groups' concept maps, including what was written and how it was displayed. These concept maps are included in Appendix A.

**What is Sustainable Design?**

During the first exercise, participation was high and a large list of concepts and ideas was created. 'Clueless' grouped its concepts into three categories: *how*, *what* and *why*. This indicated that their concept of sustainability was more than simply a list of characteristics, but also included approaches to achieve sustainability and reasons to advocate sustainability. Some of the *how* concepts included 'thinking differently', 'innovation & creativity', 'systems thinking', '(Re) education' and 'accountability'. Some of the *what* concepts included 'materials', 'energy', '100% re-use', and 'restoration preservation'. The *why* concepts included 'future generations', 'ethics / values', 'poverty eliminated', 'globalisation' and 'no warfare! Love instead'.

'Future Facilitators' identified a spectrum of ideas about sustainability from the ideological to the practical. This is akin to the duality that exists between the need for the ideological goal of sustainability that is hard to translate into individual actions, and individual actions that do not capture the full extent of the ideology behind the goal. Some interesting ideological concepts included 'For everybody, i.e. not just government / business', 'needs a long term view', 'requires a holistic perspective' and 'encourage self sustainability – personal choice'. In the transitional section, some concepts included 'raising standards of education to include global society view', 'considering all stakeholders in decisions' and 'is more than just environmental compliance'. Finally, the practical concepts included 'waste reduction', 'greenhouse gas reduction', 'efficient land use' and 'enough food for population'.

'Parhelion' split their concept map into four sections with a separation of human issues on the left and environmental issues on the right. Their key concept was that of 'human health versus natural resources', and they summarised sustainability as 'responsible governance' combined with 'triple bottom line accounting', symbolised by a circle in the centre of their map. Some other interesting concepts included 'everlasting world', ‘renewable resources’, ‘understanding how small actions fit into the big picture’, ‘social control of technology’ and ‘empowering individuals & communities’.

‘Phoenix’ grouped their concepts into four sections with no headings. Some of the interesting concepts included ‘a set of values – something personal’, ‘putting back as well as taking out’, ‘management and efficient utilisation of natural resources’ and ‘staying in business’.

**Who Cares About Sustainable Design?**

This second exercise in the workshop was to verify the stakeholder influence model developed beforehand (see Figure 5). The groups were asked to:

- Develop stakeholder groups
    - What are the subgroups of each?
    - What are some examples of each subgroup?
    - Are there any links between groups?
- Why is each a stakeholder?
    - What impact can they have?
    - How to engage them?

‘Clueless’ developed seven categories for their stakeholder groups: legislation, global, citizens, doers, moral, economists and other species. ‘Future Facilitators’ developed eight categories: everyone, government, business, community, specifics, disadvantaged, future people, and plants and animals. ‘Phoenix’ sorted their stakeholders into groups but did not name them specifically, although further analysis showed common groupings such as government, industry and the community present. ‘Parhelion’ developed a two dimensional graph with the stakeholder’s level of influence on the horizontal axis (Who don’t care – “level of influence”) and level of care on the vertical (see Figure 6). This is a novel way of classing stakeholders using two important virtues of the stakeholders’ value sets, rather than into indicative categories. It suggested that there were other ways of selecting and grouping stakeholder groups, as those groups who either care more about or have a greater influence over sustainability issues may have more experiences and hence would be better to target than those that do not.

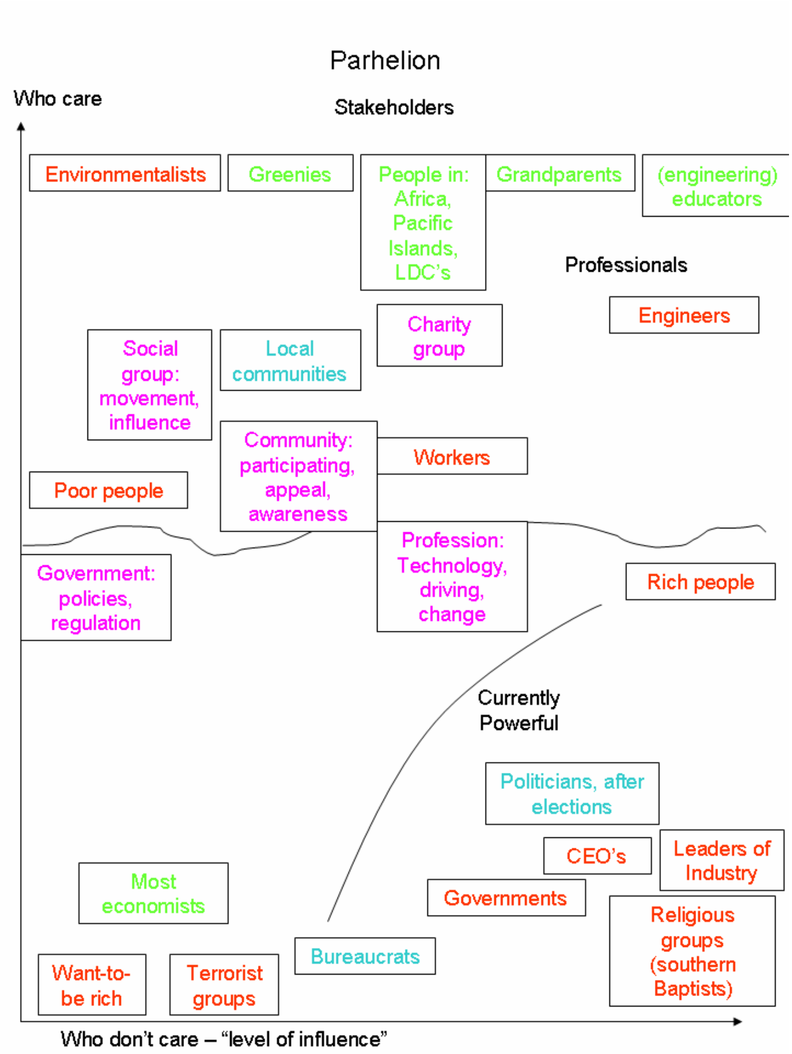


**Figure 6: Parhelion Concept Map for Who Cares?**

## What Do Students Need to Know?

This was the final exercise and was included to provide some reference concepts for future work, rather than generating first hand data. Only some of the most intriguing concepts are presented here. It is noteworthy that, although the groups were asked to look at *what* students needed to know, most ideas centred on *how* to teach engineering students about sustainability. This parallels a shift in the research questions of the thesis, from just what to teach, to also looking at how to teach students about sustainable design.

'Clueless's ideas included 'team projects for first year students – multidisciplinary teams and projects', 'sustainability needs to be integrated into our curriculum'. 'It is not a separate add-on' and 'poor attitudes: it doesn't affect software engineers'.

‘Future Facilitators’ suggested that we ‘must do more than just tell students – need to actively teach skills and techniques’. Other ideas included ‘introduce students to life cycle assessment techniques and software – small case study’, ‘sustainability becomes an actual theme in all […] teaching’ and ‘students need more tools to assess sustainability’.

‘Parhelion’s’ ideas included ‘awareness of engineering as a social activity’, ‘solar car project 1st year management’, ‘student project on world bank / IMF’ and ‘debate on wind farm locations’. Finally ‘Phoenix’ included such ideas as ‘how to think holistically to encompass ALL issues’, ‘to use their right brain’ and ‘knowledge of sustainable best practice’.

### *4.3.3 Implications from the Workshop*

The major outcome of the workshop was the realisation that the stakeholders identified in the initial model were only a small subset of all stakeholders affected by and affecting sustainability, even within engineering operations. The stakeholder influence model developed before the workshop was presented and discussed with the workshop subjects. There was general agreement that the model was good but did not go far enough. If stakeholder groups were to be investigated, as many groups as possible should at least be identified even if not included in the final thesis, so as not to miss out a key stakeholder group that may not have been initially considered.

A process was subsequently undertaken to revise the initial influence model with the stakeholder concept maps and further research. The revised list of stakeholders can be seen in Appendix B. Figure 7 displays the revised stakeholder model that was created. The initial model is shown in grey, highlighting the much more complex relationships identified. Of particular interest was the emergence of the ‘champions of sustainability’ stakeholder group. These were identified to be the individuals who were actively championing and trying to promulgate sustainability issues throughout other stakeholder groups. These champions of sustainability emerged as the focus of the study, and became ‘sustainable design practitioners’ (Mann et al., 2005).

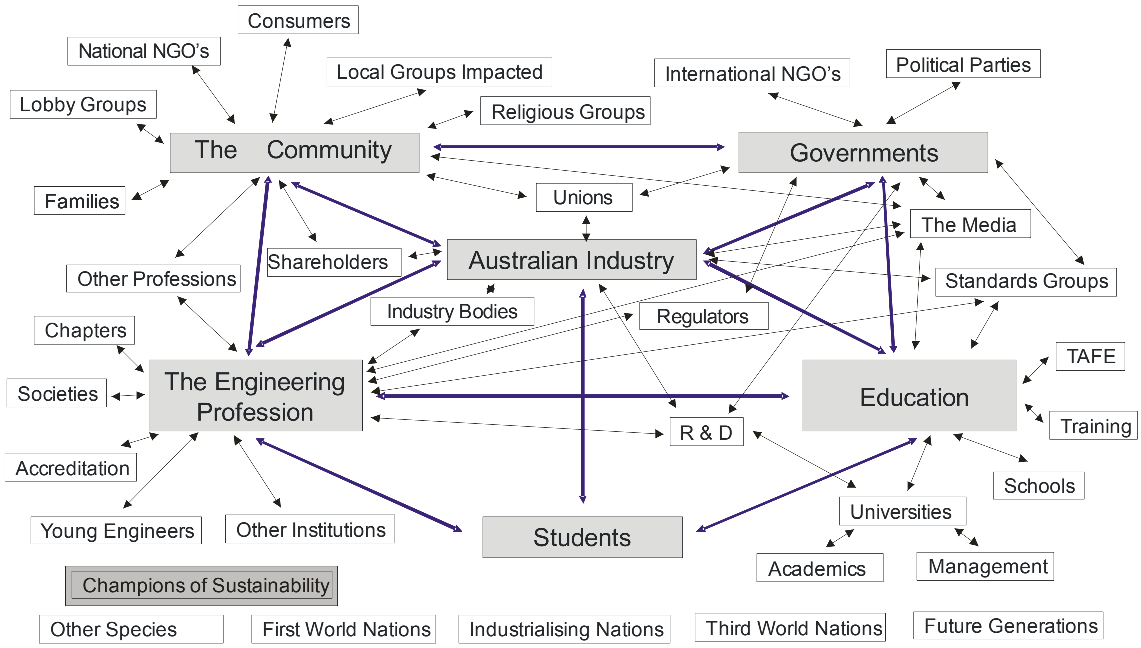


**Figure 7: Revised Stakeholder Influence Model**

This thesis looked at these sustainable design practitioners and their experiences as candidates for the interview process. These people were chosen as they had more experiences with sustainability and sustainable design from which to draw in the interviews. These people had expanded their original roles as engineers, architects or members of related fields. They had moved beyond the traditional boundaries of their profession, from being practitioners to being sustainable design practitioners. Moreover, they had become interdisciplinary practitioners, and while usually grounded in their original discipline, they had developed skills that were akin to other disciplines.

For example, the sustainable design practitioners grounded in engineering displayed abilities such as (Sustainable Consulting, 2002):

- Working with businesses, governments, the community, professional groups and educational groups;
- Having a working knowledge of sustainability, social systems, the environment, economics and stakeholder engagement;
- Having an understanding of systems thinking, project management and marketing.

These attributes went beyond those of engineering, and were more in line with other disciplines, including business, economics, ecology, anthropology, political science, social work and law. These sustainable design practitioners had the rich experiences that were needed to investigate sustainable design. The workshop also helped to elicit the names of some of these sustainable design practitioners, as discussed in Section 4.4.

Another outcome from the workshop was the suggestions about teaching engineers about sustainability. Unprompted the groups raised the issue of teaching and provided practical examples of projects. More generally, they identified the need to make students more aware of their role and responsibilities as engineers. This influenced the development of the third question of this thesis concerning how to best educate engineers about sustainable design. It seemed that developing an awareness of sustainable design was the first step in teaching students. Most students are not aware of the issues around sustainable design, and before they can be taught how to practise as a sustainable designer, they need to be made aware of these issues and why they need to know about sustainable design.

## 4.4 Sustainable Design Practitioners – The Main Study

Twenty-two sustainable design practitioners were identified and interviewed in the main study. As this was an exploratory study of experiences around engineering operations, it was important that these individuals were as diverse in rich experiences of sustainable design as possible. This helped demonstrate the range of diversity of views and experiences that exist about sustainable design, even among people dealing with it on a regular basis. Diversity was also important for the research approach, as it made a larger number of qualitatively different ways of experiencing sustainable design discernible from the infinite set, as described in Section 3.3.2. It should be noted here that diversity refers to the diversity of experiences among the subjects, and not the diversity of a single subject's experiences. The criteria used for ensuring the diversity of the twenty-two subjects are detailed in Section 4.4.2.

### *4.4.1 Methods Employed for Finding Subjects*

The identification of sustainable design practitioners was one of the major problems I recognised at the beginning of this phase of the thesis. The twenty-two subjects were selected as sustainable design practitioners according to three conditions:

- The extent of their sustainable design experience;
- Their proximity to engineering operations;
- Their accessibility to be interviewed.

The diversity of the subjects' sustainable design experiences was fundamental to both the research approach and the research questions. The subjects needed to have experiences with sustainable design to discuss in the interview. Many engineers do not have design experience, let alone sustainable design experience, so this was a necessary condition. In keeping with the phenomenographic approach, the nature of the experiences was not important, as long as the participant understood them as experiences with sustainable design.

The proximity to engineering operations was important, as one of the aims of the thesis was to help inform the education of future engineers about sustainable design. As such, the focus was not just on sustainable design, but on sustainable design within engineering operations; operations that engineers would be expected to work on in the future. As the subjects chosen were both engineers and non-engineers, the non-engineers were selected based on their experiences working on engineering projects.

The accessibility of prospective informants was important for the logistics of the thesis and the resources required. Subjects were thus chosen according to their availability and location. In many cases this restricted the focus to people within fifty kilometres of Brisbane, but did include some people from across Australia and some with international experience.

I selected the subjects in a sequential manner, based partially on how much they broadened the diversity of the group, as well as the depth of experiences that they had. A purposeful sampling technique (Creswell, 2003; Patton, 1990; Silverman, 2005) was used as a basis for the selection in order to "best help the researcher understand the problem and the research question" (Creswell, 2003, p184). This involved looking for people who were recognised as leaders in sustainable design practice, either through winning awards, working on particularly 'sustainable' projects, or just by word of mouth and reputation. This process was augmented with other strategies such as snowballing and opportunistic strategies (Marshall & Rossman, 2006; Patton, 1990). This enabled both subjects and others close to the thesis project to recommend further people to contact as possible subjects. "Can you think of anyone else that would be good to interview?" was asked at the end of the most of the interviews to find further subjects.

Using these techniques, I identified twenty-two subjects. The first stage was selecting people already known and identified as sustainable design practitioners. The pilot study, as discussed in Section 4.3, helped to identify two subjects, **Emma** and **Larry**, both of whom I knew prior to the workshop. Other existing connections resulted in a further four subjects, **Richard**, **Uma**, **Danny** and **Gary**. This opportunistic technique (Marshall & Rossman, 2006) netted six subjects in total, all engineers from different industry sectors.

The snowballing technique (Patton, 1990) provided most of the final subjects, as many of the people interviewed were aware of others in the field. Three subjects, **Thomas**, **Amy** and **Brett**, were even recommended by two or three other people, confirming their status as perceived leaders in sustainable design practice. In total, thirteen of the subjects were recommendations of other people, these being **Walter**, **Zach**, **Xander**, **Celia**, **Henry**, **Peter**, **Kelly**, **Fiona**, **Max** and **Natalie**.

The other major sampling technique used, known as extreme sampling (Patton, 1990), involved the identification of subjects who either won awards themselves or were involved with projects that had won awards for sustainable design. In winning an award, the subjects had identified themselves as champions in the practice of sustainable design. Six of the subjects were identified in this way, with many of them also being identified using the snowballing technique. These subjects were **Jacob**, **Thomas**, **Simon**, **Amy**, **Isaac** and **Brett**.

### *4.4.2 Diversity of the Subjects*

This section presents the diversity criteria I used during the selection of the twenty-two subjects. The diversity of the subjects was important from the point of view of both the research approach and the generalisability of the final results. Each criterion was broken into different categories aimed at reflecting the diversity of interest. The criteria used were:

1. Industry Sector
2. Project Scale
3. Geographic Location
4. Type of Client
5. Stakeholder Group
6. Professional Discipline
7. Years of Experience with Design
8. Formal Training in Sustainable Design
9. Gender

Table 5 presents the subjects and how each fit the diversity criteria. The numbers associated with each participant represent only the order in which they were interviewed. The totals down the right side are not necessarily 22, as participants may be in more than one section in each category.

**1. Industry Sector**

The industry sector or sectors in which the participant had experience served as the main source of diversity. This was because of the significantly different conditions and challenges that the different sectors face. This criterion was used to obtain a spread throughout the categories of Construction, Community / Building, Resources, Product / Manufacturing, Education or Individuals of Interest. As the experiences of the subjects had to relate to engineering operations, the industry sectors chosen were inclusive of almost all engineering work in the area of sustainable design. It also included education, as some engineers in the education sector have experience with sustainable design through previous industry experience, consulting work, or researching of sustainable design practice. Individuals were also identified to be of interest if they had many experiences with sustainable design, but not from one particular industry sector.

**Table 5: Diversity of Subjects**

| Number | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Participant | | Emma | Richard | Walter | Uma | Jacob | Danny | Zach | Thomas | Larry | Simon | Xander | Gary | Celia | Amy | Henry | Isaac | Peter | Kelly | Fiona | Max | Natalie | Brett | Total |
| Industry Sector | Con | | | | | | | | | x | | x | x | x | | | | x | | | | | | 5 |
| | ComB | x | | | x | x | | | x | x | x | | | | x | | | x | x | | | | x | 10 |
| | Res | | x | x | | | | | | | | x | x | | | x | | | | | | | | 5 |
| | Prod | | | | | | x | x | | | | | | | | | x | | | | x | x | | 5 |
| | Indiv | x | | | | | | | | | x | | x | | | x | | | | x | | x | | 6 |
| | Edu | x | | | | | x | | | x | | | | x | | | | | x | x | | x | | 7 |
| Project Scale | Comp | | | | | | | | | x | | x | x | | | x | | | | | | | x | 5 |
| | Large | x | x | x | x | | | x | x | x | x | | | x | x | x | | x | x | x | | x | x | 16 |
| | Small | | | | | x | x | x | x | x | | | | | | | x | | | x | x | x | | 9 |
| Geographic Location | Rural | | x | x | x | | | | x | x | | | | x | x | x | | | x | | | | | 9 |
| | Metro | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 22 |
| | Inter | | | x | | | | | | x | | x | x | | | x | x | | x | | x | | | 8 |
| Type of Client | Pub | | | | | | | | | x | x | x | x | | | | | x | | | | | x | 6 |
| | P/P | | | | | | | | | | | x | x | | x | | | x | | | | | | 4 |
| | Pri | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 22 |
| Stakeholder Group | Indus | x | x | x | x | x | | x | x | x | | x | x | x | x | x | x | x | x | | x | x | x | 19 |
| | Gov | | x | x | | | | | | x | x | | | | | | | x | | | | | | 5 |
| | Uni | x | x | x | | x | x | | | x | | | | x | | | | | x | x | x | x | | 11 |
| | Prof | x | | | | | | | | x | | | | | | | | | | | | | | 2 |
| | NGO | x | | | x | | | | | | | | | | | | | | x | | | | | 3 |
| Professional Discipline | Eng | x | x | x | x | x | x | | | x | | x | x | | | x | x | x | | | | x | x | 14 |
| | Non | | | | | | | x | x | | x | | | x | x | | | | x | x | x | | | 8 |
| Years of Experience with Design | <5 | | x | | x | | | x | | | | | x | x | | | | | | x | | | | 6 |
| | 5 - 15 | x | | x | | | x | | | | | | | | | x | x | | x | | x | x | | 8 |
| | 16+ | | | | | x | | | x | x | x | x | | | x | | | x | | | | | x | 8 |
| Formal Training of SD | Y | x | | | x | x | | x | x | | | x | | | | | | x | x | x | x | | | 10 |
| | N | | x | x | | | x | | | x | x | | x | x | x | x | x | | | | | x | x | 12 |
| Gender | F | x | | | x | | | | | | | | | x | x | | | | x | x | | x | | 7 |
| | M | | x | x | | x | x | x | x | x | x | x | x | | | x | x | x | | | x | | x | 15 |

## 2. Project Scale

The project scale was included as subjects working on smaller scale projects were predicted to have vastly different experiences compared to those working on large, multi-national projects. The categories used were complex, large and small, and reflected the size and associated cost of the solution being developed. Complex projects were mainly international or multi-national, many-million dollar projects, or projects that had many different disciplines working together on a solution with many smaller facets. Large projects were multi-million dollar projects that consisted of work on a single entity, be it a building, a mine or a plant that had different disciplines working together. Small projects were smaller single entities that were typically less than a million dollars in value. These could take the form of a house, a car or a domestic appliance. The categories were not regarded as mutually exclusive; that is, a participant may have experience in all three categories.

**3. Geographic Location**

Geographic location, while similar to the scale of projects in terms of the diversity it can provide, is important as local conditions and cultures can have an impact on the subjects' experiences of sustainable design. The categories for the geographic location were rural, metropolitan and international, with a participant able to have experiences in any number of these. Rural referred to projects outside major cities, metropolitan, projects within major cities, and international to projects with links outside Australia.

**4. Type of Client**

The type of client was included as the challenges in a publicly versus privately funded project were predicted to be vastly different, particularly with respect to sustainable design. The three categories used were public projects, public – private partnership projects, or private projects. It should be noted that these three were not regarded as mutually exclusive; that is, a participant may have experience in all three categories. Public projects were those that had government sources of funding and were for government works, either at a federal, state or council level. Private projects were run by a private corporation. Public – private partnerships were projects where funding came from both the private and the public sector, and are typically larger, more complex projects.

**5. Stakeholder Group**

The stakeholder group was another important diversity indicator, and represented the different group or groups that the participant was associated with. The major stakeholder groups used for this study were industry, government, education, the engineering profession, and non-government organisations. These paralleled the major groups identified in the initial stakeholder influence model presented in Section 4.3, as they contained the vast proportion of subjects. Industry represented people in private companies involved with engineering operations. Government included both government representatives and engineers working for the government rather than a private entity. Education included academics or other research staff involved with educating students or research in sustainable design within a university context. The engineering profession included people who had particular roles within professional organisations, rather than simply membership of those organisations. Non-government organisations (NGOs) included people who may be involved in another group as a professional, but also be part of a NGO oriented towards sustainability issues. It was predicted that people from these different groups would have diverse experiences of sustainable design.

**6. Professional Discipline**

In order to look beyond the current practice of engineers, a number of non-engineers, still involved with engineering design activities, were included under the professional discipline criterion. These non-engineers included architects, environmental scientists and industrial designers. These categories were considered mutually exclusive. In the case of a participant who was both an engineer and architect, their placement depended on which group the participant identified with. A ratio of two thirds engineers to one third non-engineers was desired to reflect the emphasis on engineering projects but also incorporating other disciplines.

**7. Years of Experience**

The years of experience in design was included so as to maximise the variation of professional experience of the subjects. Experience of design, and not sustainable design, was used to allow for the fact that a participant may be an experienced designer but have relatively little experience of sustainable design. Conversely, it was thought that the less experience the participant had, the less they may be fixed to a certain 'way of doing things' and thus could be more open to dealing with sustainable design issues. It was anticipated that roughly a third would come from each of the three levels of interest. These were defined as 1 - 5 years experience (level 1), 5 – 15 years experience (level 2), and 15 + years experience (level 3). These were regarded as mutually exclusive categories. This criterion was used as an introductory question in the interviews to develop an understanding of the background of each participant.

**8. Formal Training in Sustainable Design**

Formal training in sustainable design was a yes or no category and was determined by a preliminary question in the interviews. This also helped to develop a clearer picture of the participant's background and possible knowledge base about sustainable design. This was important because of the possibility of the participant giving an academic definition of sustainable design, based on what they had been taught, rather than their experiences of sustainable design.

**9. Gender**

Gender was the final criterion and identified as an important source of variation in ways of experiencing an aspect of the world (Hazel et al., 1997). The percentage of females in engineering in Australia is currently about five and a half percent, and about fifteen percent in engineering education programs (Women in Engineering, 2005). When selecting subjects, at least fifteen percent female was the target, in line with these trends. However, as the sample was not meant to be representative of the population, having a minimum of fifteen percent female was as much an ethical issue as a source of diversity ((National Health and Medical Research Council, 1999), see also Section 4.8). The final sample contained just over thirty percent female (seven out of twenty-two), which again was not representative but gave arguably a greater diversity of experiences than just fifteen percent female.

These criteria were used throughout the selection process of subjects and were kept in mind as new subjects were identified to ensure that a diverse final group was obtained. The position of the participant in most of the categories was derived from the experiences talked about in the interview or through prior contact, except for the years of experience with design activities and formal training in sustainable design, as these were ascertained in the beginning of the interview (see Section 4.5.2).

# 4.5 Collection of Data

This section provides a detailed description of the phenomenographic data collection process I used in this thesis. The data collection consisted of twenty-two semi-structured, in-depth interviews, conducted with each of the identified subjects. Interviews are the most commonly used method for accessing experiences in phenomenographic research (Marton & Booth, 1997).

It was important that before any of the final subjects were interviewed, I conducted pilot interviews to gain experience with the interviewing technique (Bowden, 2005; Green, 2005). Two pilot interviews were conducted with colleagues using a preliminary interview protocol. The colleagues involved had some experience with sustainable design and were both based at the University of Queensland. Their interview transcripts were not included in the main thesis study, and used only to refine the interview technique and protocol. After each pilot interview, I reviewed a recording of the interview to improve my interviewing technique and examine how well the interview questions had worked. Through this iterative process, the interview technique, as well as the interview protocol itself, was enhanced.

After the pilot interviews were completed, twenty-three subjects were contacted by letter with a follow up telephone call or email explaining the study, what their involvement in the study would entail, and that the study had been approved by an ethics committee of the University. The letter I sent to subjects is presented in Appendix C. Once contacted, a date, time and place were set for each interview. Only one person I approached declined to be involved, with the final number of participants twenty-two.

Most interviews took place either in the participant's office or in a private room at the University of Queensland, whichever was easier for the participant. In some cases, a third venue was found, as the interview was conducted away from both the University and the participant's work environment. Arrangements were made to minimise possible interruptions, especially when the interviews were conducted in the participant's office. On average, the interviews lasted forty-five minutes, but ranged between half an hour to up to an hour and a quarter, depending upon how much time the participant had available and the flow of the discussion.

I used a set of semi-structured, open ended questions within the interview protocol (see Appendix D), with follow up questions seeking clarification of terms and ideas the interviewee relayed. The interview protocol also helped me to ensure proper phenomenographic practice, and tried to capture some of the diversity criteria of the interviewee. Additional follow-up questions I asked spontaneously during the interview encouraged the subjects "to give full explanations of their understanding by nondirective questions such as 'Could you explain that further?', 'What do you mean by that?', 'Is there anything else you would like to say …?'" (Bowden et al., 1992, p263). Within the interview, it was important that the subjects talk about their experiences with sustainable design, and that they were not led into some kind of 'meta-talk' about issues (Säljö, 1996), providing either corporate rhetoric or baseless speculation.

I found the reminders at the start of the protocol very useful, especially in the first few interviews, to ensure a consistent approach between interviews. A brief background to the study was presented to allow the subjects to give informed consent to their involvement. I asked two introductory questions about the level of experience of design activities and formal training in sustainable design. It should be noted that these were the only two diversity criteria that were directly asked of the subjects, as they could not be ascertained easily by other means.

The body of the interview made up the core data for the thesis. As shown in the interview protocol (Appendix D), subjects were asked to describe an experience they had that involved sustainable design. They were not confined to talking about a particular experience, because the experiences they selected to discuss help to illustrate the way they experience sustainable design (as discussed in Chapter 3). The follow up questions in this part of the interview were all aimed at eliciting what was meant by certain words or concepts the subjects used, instead of assuming what was implied. I asked the subjects directly to describe what they meant by terms, and in many cases, how important they considered them for sustainable design. Throughout the interview, I ensured that subjects kept talking about their experiences, and what their role was, rather than describing generally what was done by others.

Rather than simply a question and answer session, the interview was a dialogue and a process of reflection about sustainable design for the subjects. The questions in the conclusion stage of the interview were aimed at consolidating the subjects' reflections. Asking subjects to try to sum up sustainable design at the end of the interview meant their answers were more likely to be based on their reflections and the experiences they discussed in the interview. If subjects had been asked to reflect on sustainable design at the beginning of the interview, they could have engaged in the kind of 'meta-talk' that Säljö (1996) criticises.

Three concluding questions were aimed at revealing other critical experiences the subjects may have had. In particular, an experience that challenged the way the subjects thought about sustainable design was included, as sustainable design was identified as a value laden concept in the planning of the thesis. Thus, experiences that made the subjects change or question their understandings could help further illustrate the way they experience sustainable design. The final question allowed subjects to express something they felt was important to them about sustainable design, but that may not have been discussed during the interview. This turned out to be a key opportunity for some.

All interviews were digitally recorded and later transcribed *verbatim*. These transcriptions were done as soon as possible after the interviews to allow for reflection on and refinement of the interview technique. The transcripts and recordings were handled and stored in accordance with the ethical issues identified in Section 4.8. The interviews were conducted over a period of four months, between September and December, 2005.

# 4.6 Analysis of Data

This section presents an account of the data analysis process I undertook in this study. The process was an iterative one, constantly grounded in the interview data. Once the interviews were recorded, they were transcribed *verbatim*. This *verbatim* transcription was important, as not only was what the participant said significant for the phenomenographic process, but also how they said it and in what context. The same term or phrase could be used in different contexts to mean different things by different subjects, or conversely different subjects may use different terms or phrases to mean similar things. In phenomenographic analysis, the context of utterances is important (Sandberg, 2005).

I de-identified the transcripts as they were transcribed. Each participant was given a pseudonym that was used during the subsequent analysis and presentation of the findings. Also, any identifiable names, such as the names of projects, people or places were removed and replaced by the general term in square brackets. For instance, the utterance of a particular project was replaced by [project]. A part of a sample interview transcript can be seen in Appendix F. All twenty-two interviews were transcribed in this way, with the transcriptions becoming the data for the analysis process.

The first step in the analysis of the transcripts involved trying to develop a statement for each transcript as to what sustainable design was. These were used as pragmatic 'handles' to aid in the analysis process without getting too focused in the detail too early in the process. The transcribed interviews were all read and re-read to familiarise myself with each transcript. As a transcript was read through, I kept the statement 'Sustainable design is…' in mind to try to develop a statement of what sustainable design was for that transcript. Critical statements about sustainable design were identified throughout the transcript, and while these helped focus the analysis process, they were used within their context in the transcript as a whole, as a 'whole of transcript' approach was undertaken. These statements were identified as they demonstrated a key aspect of how the subjects related their experiences of sustainable design.

In a first attempt, individual statements as to what sustainable design is were identified from the twenty-two transcripts. In identifying the ways of experiencing sustainable design, I focused on what sustainable design is, rather than what needs to happen to achieve sustainable design. For example, the statement derived from Larry's transcript was "Sustainable design is a holistic process of designing efficient solutions to problems that takes into account responsibilities to society and the environment." The focus that Larry has on a holistic design process is central to what sustainable design is for him. Henry's way of experiencing sustainable design was identified as "Sustainable design is an approach on both a professional and personal level to understand processes simultaneously at a holistic, systems level and at a detailed level, in order to have a restorative effect on the environment and society." I continued this process of the iterative identification of the individual ways of experiencing sustainable design for all twenty-two transcripts, each backed up with a set of illustrative quotes. These became the basis for the evolution of the categories of description of sustainable design.

The individual statements of sustainable design for each transcript were compared, looking for similarities and differences that would reveal key, qualitative variations in this aspect of the world. Transcripts were grouped by key similarities and differences in the individual way of experiencing sustainable design. As discussed in Section 3.4.2, the structure of the variations also started to become apparent (as Åkerlind (2005a) also asserts) and was used to further examine the variations between categories. For example, both Henry and Larry have a focus on sustainable design as a holistic process. Henry, however, sees sustainable design as not just taking into account the responsibility of engineers in the design process, as Larry does, but on designs having a restorative effect on the environment and society. These similarities and differences became the basis of the next step of the analysis process, in which similar ways of experiencing sustainable design were grouped in forming draft categories of description. The first draft set of categories of description can be seen in Appendix G.

The first major difference that became apparent from the interviews was the focus on either finding a solution or solving a problem. For those subjects who talked about sustainable design as finding a solution, the solution itself took the form of either a final physical product or the processes in developing a product. The product / process variation came from the variation in experiences of the subjects. The product engineers talked about the product, for example a refrigerator or a car, whereas the process engineers talked about the processes of producing the final product, for example the processes to produce a refined metal, or a petroleum product. For those that talked about solving problems, the problems discussed were either those supplied by a client, or the client's problem seen as part of a larger set of social problems.

There was a group of transcripts in which sustainable design was spoken of as not just solving problems as a designer, but as a person. Sustainable design was a way of framing lives, and these subjects talked about experiences of sustainable design applied within their lives. This included designing their own house, or encouraging others to adopt sustainable practices in their lives. This group of transcripts was also seen from a structural point of view to be more comprehensive than the others. The subjects were not only talking about sustainable design as a professional activity in the way the others were, but as a personal framework.

Once the transcripts were grouped, I read and reviewed them again and whether or not they fit within the group they had been assigned to. I asked the question: 'Is there another way of interpreting this statement or this transcript as a whole within the emerging group?' If a more convincing interpretation became apparent, the transcript was moved to a different group and a new description of that group formulated. Through this iterative process, six distinct groupings began to emerge with a critical variation between each.

Once the groupings had been developed, the transcripts that made up each were analysed again and a statement explaining the commonality was developed. Each statement was illustrated with quotations taken from the transcripts. The descriptions of the groupings related to the transcripts in the grouping only, and made no mention of or comparison to the other groupings. As the descriptions of the categories were tightened and reviewed, the distribution of the transcripts across the categories was modified. Three transcripts were moved to different groups after the initial groupings. This led me to further redevelop the descriptions of the groups. The fourth and sixth iteration of the categories of description can be seen in Appendix H and I respectively.

During this time, I also developed a diagram for each of the categories of description. These were used to enable further discussion and iteration of the similarities and differences between the categories. In particular, they helped to specify the key variation and structural relationships between categories. This led to a review of the first two categories, those concerned with finding a solution. While there was variation between them, it was not as large as the variation between the other categories. Also, while one category focused on producing a product, it also mentioned the processes that went into producing that product. Likewise for the processes category, there was still talk of the product, but the focus was on the processes. Consequently, I decided to combine the two into one category, with a minor variation within the category as to the form of the solution, either product or processes.

After the categories of description had been further refined, labels were developed for the five categories to help in their presentation. The diagrams were also refined, and illustrative quotes were chosen to further illustrate each category. Chapter 5 presents the final results of this analysis process. In all, the categories of description underwent eight iterations.

# 4.7 Ensuring Validity and Reliability

This section argues for the validity and reliability of the results presented in Chapter 5. It is based on the material presented in Section 3.5. An argument for the generalisability of the results is made in Chapter 6.

## *4.7.1 Validity*

Two types of validity were used in this study, those of communicative validity, and to some extent, pragmatic validity. As discussed in Section 3.5, Sandberg (1994) proposes three phases in the phenomenographic process where communicative validity is relevant: (i) within the interviews communicating with the subjects; (ii) in the analysis process communicating with the text; and (ii) in communicating the results to other researchers and professionals.

For the first phase of communicative validity within the interviews, subjects were informed prior to the interview that I was interested in their experiences of sustainable design. They were also informed that there were no right or wrong answers, and that no personal judgements would be made about what was discussed. This was to start to develop a joint understanding between the subject and I about what was being discussed in the interview (Sandberg, 1994). The other aspect of communicative validity in this phase is establishing a dialogue within the interview, rather than the interview becoming a question and answer session. This was achieved by having a specific interview protocol with a set of open ended initial and follow up questions to stimulate discussion, rather than asking questions of a closed nature. Also, within the interviews I constantly asked for qualification of statements the subjects made as a way to stimulate further discussion.

For the second phase of communicative validity proposed by Sandberg, the focus within the analysis process was always on the transcripts as wholes, rather than trying to extract parts of the transcripts and analyse them out of context. The focus was maintained on looking at the similarities and differences between whole transcripts, especially where a particular statement taken out of the transcript may appear to fit into one category, but when seen within the whole transcript fits into another category. For example, at one point in her interview, Celia stated that 'sustainability in its truest sense… really needs to be looked at holistically'. Out of context this statement could fit into a more comprehensive category, yet throughout the rest of the interview she discussed her actual experiences in terms of finding a solution, a less comprehensive category.

The third phase of communicative validity involves obtaining feedback from other researchers and professionals, in this case in sustainable design. The results were communicated and developed with my advisors as examples of other researchers in the field. The feedback was positive in that the results seemed to make sense from engineering, design and sustainable design perspectives.

The results were also communicated to a group of fifteen practising sustainable designers, both engineers and non-engineers. While two of the subjects interviewed to generate the categories of description were present, it was not the focus of the feedback to validate their placement within the categories. The general group responded positively to the categories, and understood that they showed that while everyone was 'doing sustainable design' there are still differences based upon individuals' previous experiences. The practicing engineers could also see implications for the practice of sustainable design, particularly with the change in focus from finding a solution to solving a problem, as well as seeing problems within a wider societal context (see Table

6 in Chapter 5). This feedback from the group of professionals was also relevant to the pragmatic validity of this study. While pragmatic validity usually involves applying the outcomes of research in practice and seeing whether or not practice has improved, this is outside the scope of this study. However, the group of professionals could see how the results could be applied to their own practice.

### *4.7.2 Reliability*

Reliability in this phenomenographic study revolves around my interpretive awareness, or how I have controlled and checked my interpretations throughout the research process (Sandberg, 1997; 2005). The processes for ensuring reliability in this research also builds on Green's (2005) idea of rigor in a phenomenographic study. As discussed in Section 3.5.2, the stages where my interpretations were controlled and checked were:

1. The formulation of the research questions;
2. The selection of the subjects;
3. Interviewing those subjects;
4. Analysing the resultant transcripts;
5. Reporting the final categories of description.

1. The research questions for this study aimed to elicit the variations that existed among practitioners' experiences of sustainable design. Of the three research questions, the first asked what were the variations in ways of experiencing 'sustainable design' among the sustainable design practitioners interviewed. The other two questions concerned the implications of the results from the first question for sustainable design practice and sustainable design education. The questions were formulated with a focus on exploring variation in ways of experiencing sustainable design, rather than trying to test or impose a preconceived theory.

2. In selecting the subjects, a set of specific criteria were used to ensure variation in the experiences of the subjects (as discussed in Section 4.4.2). These criteria were developed from the literature and ensured that I did not select participants based upon what I believed sustainable design to be. Rather, as discussed in Section 4.4.1, most of the subjects were identified either as leaders in the practice of sustainable design through awards and the like, or identified by others in the field as persons of interest.

3. During the interview process, my interpretations were controlled and checked in a number of ways. Before interviews began, two pilot interviews were conducted to develop my interviewing skills as well as the interview protocol, as discussed in Section 4.5.1. In this way, I learned to focus on what sustainable design meant for the subject, rather than bringing in my own preconceptions or theories into the interview discussions. The interview protocol was also developed so as not to ask leading questions, or questions that suggested a particular way of experiencing sustainable design to the interview subjects. The interview protocol also aided in making the interviews as consistent as possible. Each interview started with the same information and introductory questions, and ended with the same concluding questions.
During the interviews, an open-ended but focused interviewing technique was used. This allowed the subjects to focus on the aspects of sustainable design they believed were important rather than 'fitting in' to any preconceived theories. The technique was focused in that the subjects were constantly asked how what they were talking about was related to sustainable design, rather than me trying to focus the interview based upon what I determined to be important or not.

4. In the analysis process, the main control of my interpretations was a strict adherence to data in the form of the twenty-two interview transcripts. This involved constantly going back to the data as a whole, and reading statements in context during the analysis process. It also involved admitting to inconsistencies between transcripts during the analysis process, rather than trying to constrain data to appear consistent. The categories were developed in an iterative fashion, in which the inconsistent transcripts acted as prompts for a different way of viewing the categories of description. Finally, my advisors took the role of devil's advocates during the development of the categories, constantly questioning my interpretations. As discussed in Section 4.6, while the outcome space was developed as the categories were developed, this structure was also subject to constant questioning during the analysis process.

5. The final results, presented in Chapter 5, are in the form of a set of categories of description that form a hierarchical outcome space. The descriptions of the categories are based on the transcripts, and include illustrative quotes taken from some of the transcripts to further check my interpretations.

## 4.8 Ethical Considerations

This thesis was conducted ethically and in accordance with all relevant policies and procedures. This included the University of Queensland's Research Ethics Policy (UQ, 2002) and the National Health and Medical Research Council's national statement (National Health and Medical Research Council, 1999) that applies to research conducted in Australia involving human subjects. The guiding principle of ethical conduct is integrity, including the conducting of research, and the dissemination and communication of results in an honest and ethical manner (National Health and Medical Research Council, 1999). Research involving humans, such as in this study, includes regard for the welfare, rights, beliefs, perceptions, customs and cultural heritage of the persons involved. In the case of this study, the good image of the University of Queensland and the academic community was also considered (UQ, 2002). This study did not involve any vulnerable groups, (NHMRC, 1999), and no subjects were put at risk outside of those of a normal office environment (Creswell, 2003).

The main ethical considerations for this study were the relative inexperience of the researcher, potential conflicts between participants and employers, obtaining the informed consent of the subjects, and the confidentiality and de-identification of the subjects, including data storage and handling arrangements, as well as reporting the results of the study. These issues are discussed in Sections 4.8.1 and 4.8.2 respectively.

An ethical consideration was whether I had the necessary skills and experience to conduct the research. To address this, supervised pilot interviews were undertaken as a way of developing the necessary skills and techniques related to interviewing and transcribing the data using a phenomenographic approach. Also, regular feedback was obtained throughout the interview and data analysis process. Another ethical consideration was the potential conflict between a participant and their employer about being involved in the study. To address this, the subjects were encouraged to be as open as possible with their company about their involvement in order to maintain the good name of the university, as well as to avoid any ethical complications or infringements. If the company believed the participant should not be part of the study, then another participant would have been found with no judgements made about the withdrawing subject. In reality, no one declined participation.

### 4.8.1 Informed Consent

All subjects interviewed in this study provided their informed consent in the form of both a verbal agreement and a written, signed consent form prior to the interview. The written informed consent form is shown in Appendix E. Before giving informed consent, subjects were firstly informed both verbally and in writing that their involvement was voluntary, about the nature and purpose of the study, and about procedures for their involvement. They were informed that the interview would be recorded and later de-identified, and that they had the opportunity to withdraw any statements they made during the interview at any time during or after the interview without judgement or prejudice, in accordance with the necessary guidelines (National Health and Medical Research Council, 1999). The benefits of their involvement in the study were also explained to subjects. These included a greater awareness of what sustainable design meant for them through the stimulated reflective processes in the interview, as well as access to the final results.

### 4.8.2 Confidentiality and the De-identification Process

One of the main ethical considerations for this project was confidentiality, specifically related to company information and commercial in-confidence. Since the subjects were to relate their experiences of sustainable design through experiences within actual engineering projects, what they revealed about companies, governments or other groups could have had confidentiality issues.

To address this ethical consideration, the subjects for this study were interviewed in a private location with the interview recorded and later transcribed verbatim. Once transcribed, the data was de-identified to establish confidentiality and anonymity, only the de-identified transcripts were used for the data analysis. The original tapes and transcripts from the interviews were kept in a locked cabinet. Only the advisory panel and I were privy to the transcripts. In reporting the results, care was taken to protect the identity of interviewees at all times, including within quotations.

## 4.9 Conclusion

This chapter presented the design and analysis of the phenomenographic study of sustainable design at the core of this thesis. The validity and reliability issues were also discussed, as were the ethical considerations. Chapter 5 presents the results of the study described in this chapter.

# 5 WAYS OF EXPERIENCING SUSTAINABLE DESIGN

## 5.1 Introduction

This chapter presents the primary results of this thesis, which are five qualitatively different categories of description of sustainable design. These represent the critical variations of the interviewed sustainable design practitioners' experiences with sustainable design[7]. These results are presented in Section 5.2 in the form of an outcome space, or a hierarchical representation of the categories of description. This section includes an overview of the categories and their structural relationships. In Section 5.3, expanded descriptions of the categories are provided. It should be noted here that the categories of description were developed from what the subjects have said in their interviews; there has been no extrapolation from the interview data. The critical variations and relationships between the categories are presented and explored in Section 5.4, with Section 5.5 examining the distribution of subjects across the categories. An analysis and discussion about the categories of description and their implications for the practice and education of sustainable design is given in Chapter 6.

[7] For clarity, 'categories of description' will be used from now on as short hand for 'qualitatively different categories of description of sustainable design'.

## 5.2 Outcome Space of Sustainable Design

The outcome space presented in Table 6 represents a summary of the five qualitatively different ways of experiencing sustainable design derived from the interview transcripts. Three major structural groupings were identified for the categories of description, those of solution focused, problem focused and social network focused approaches to sustainable design.

**Table 6: Outcome Space for Sustainable Design**

| | Category of Description Name | Description |
|---|---|---|
| Solution Focused | **Category 1** Solution Finding | Sustainable design is finding a solution, either a product or process(es), to satisfy a client's declared requirements while decreasing the associated environmental, social and economic impacts. |
| Problem Focused | **Category 2** Reductionist Problem Solving | Sustainable design is the process of identifying and solving a client's problem by making separate decisions that each decrease the associated environmental, social and economic impact. |
| Problem Focused | **Category 3** Holistic Problem Solving | Sustainable design is the process of identifying and solving a client's problem holistically on a systems level, to increase the environmental, social and economic value of the solution. |
| Social Network Focused | **Category 4** Social Network Problem Solving | Sustainable design is the process of identifying and solving a client's problem, embedded within a wider societal context to increase the environmental, social and economic value of the solution to both the client and society. |
| Social Network Focused | **Category 5** A Way of Life | Sustainable design is a way of approaching life where all the activities engaged in aim to increase the environmental, social and economic value of the outcome to both the individual and society. |

The solution focused group looks at finding a specific solution within the already declared requirements of the design. The distinction between solution focused and problem focused is the change from looking to find a solution to a client's already declared requirements, to identifying in collaboration with the client, what the client's problem actually is and developing the requirements from that to find a solution. Social network focused takes this a step further with the designer looking at the client's problem within the context of a larger set of problems facing society, and finding a solution as much for the larger set of problems as for the client's problem.

## 5.3 Categories of Description of Sustainable Design

This section presents the qualitatively different categories of description of sustainable design that were developed from the twenty-two interview transcripts. Five categories were developed, each representing a qualitatively different way of experiencing sustainable design. Each category presented in this section includes a short description, a diagrammatic representation, and an expanded description with illustrative quotes from the transcripts. All names of subjects given in this chapter are pseudonyms. The page numbers after each quote refer to the pages where the quotes appeared in the transcript (See Appendix F for longer example of an excerpt from a transcript with page numbers). The quotes are used to exemplify and clarify the categories. They are however only a subset of the whole interview, and it should be remembered that the categories were developed from the interviews as wholes, and not just from the specific quotes given. Also, not every participant is represented as the quotes were selected to illustrate the features that distinguish each category.

The term 'client' that is used throughout the categories is a general one, and refers to the body that has engaged the designer to carry out the design work. Different designers may carry out completely different work for different clients, but they are always retained by someone, be it a private company, the government, or consumers.

### 5.3.1 Category 1: Sustainable Design is Solution Finding

> *Sustainable design is finding a solution, either a product or process(es), to satisfy a client's declared requirements while decreasing the associated environmental, social and economic impacts. (n=5)*

The focus of this category is on finding a solution to a client's declared requirements. These requirements are already identified by the client and on the whole are usually non-negotiable, although a few may be negotiable in certain cases. The design process is bounded by these requirements, thus reducing the range of possible options that the designer is able to consider.

The solution is in terms of either the final physical *product* or changes to the technical and or human *processes* involved in producing the final physical product. The product or processes are 'found' as the solution as they meet the clients declared requirements. The sustainable design process is undertaken so as to decrease or minimise as much as possible the solution's negative environmental, social and economic impacts. A pictorial representation of this category can be seen in Figure 8.

This category is illustrated by Uma, who describes finding a solution to the client's declared requirements, in this case within a housing development. While efforts are made to decrease the negative environmental, social and economic impacts of the solution, they are still bounded by the clients' declared requirements:

> *Most of the people we work for aren't interesting in how we do something they're interesting in the outcome and we work as sub consultants a lot and we're told what the out desired outcome is and we're often not included in that process at all, which is incredibly frustrating because we can often see alternative solutions that we see that would be much better um, but for what ever reason they have made up their mind and usually it's because it is the cheapest option. In fact [laughs] it's always because it is the cheapest option and sometimes that cheapest option may actually been a greener solution but it's cheaper for them because they will sell more properties. (p2)*

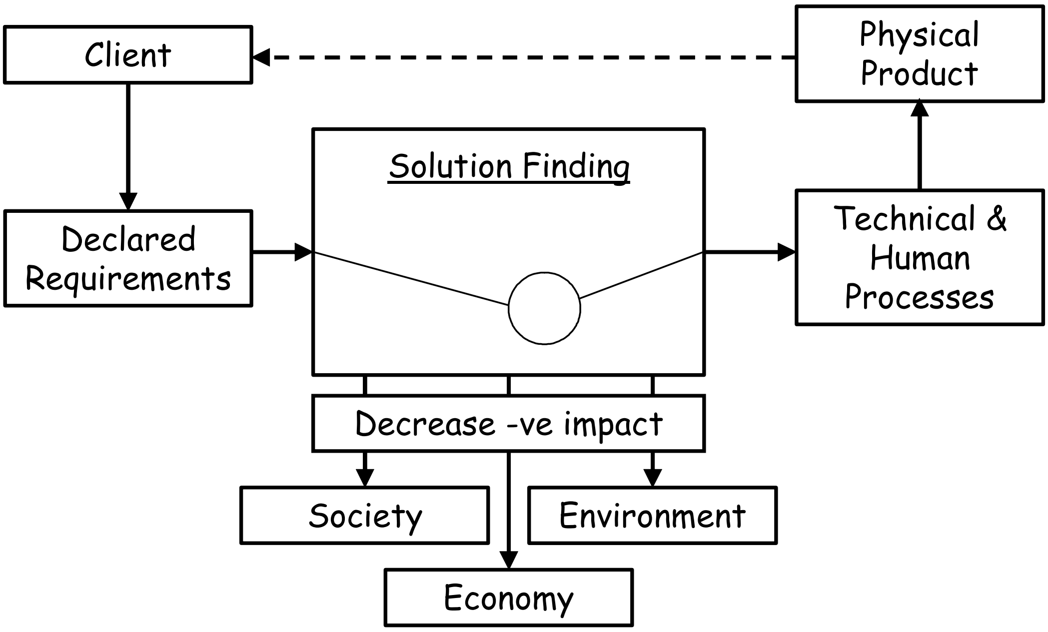


**Figure 8: Category 1 - Sustainable Design is Solution Finding**

Within this category, there is variation in the form that the solution takes. This is illustrated in Figure 8 where the physical product and the technical and human processes are outcomes of the solution finding process. Both are always present, but one or the other is selected as the focus of the sustainable design process.

Max describes the solution as a product that has to meet the client's declared requirements, in this case of function, aesthetics, safety and cost, while trying to decrease its associated impact. The processes that develop the product are still considered, but the sustainable design activity is focused around the design of the product itself:

> *Sustainable design to me is the, the production or the manufacture of of products, I'll keep it to products, that meet your, you know, basic requirements of function, aesthetics, safety, cost but also, on top of that and it's part of the whole, it's not something that's added on, is the concern for the environment and the awareness of the environment ... which is given just as much weighting as any of the other ones. (p8)*

In contrast to Max, Celia focuses on changing the human processes as sustainable design. A final physical product is still developed, in this case a building, but the focus is on changing the processes used to create the product:

***Celia:*** *One of our project managers came from a trade background … if you like on the ground and so he didn't necessarily see any usefulness in any of this [sustainable design]. He could appreciate it but in reality, what the builders do and the tradies do was not necessarily in line with it and it was all given lip talk to, and so it was trying to change his viewpoint, well you know the '[The boss] says' helps because he doesn't have a choice. He needs to ensure that they have this [design] plan filled out, the the [sustainable design] matrix done and everything else and it's also taking new products to them and trying to … get them thinking you know, what it all means and actually look for projects you know, products themselves so I, they'll actually come to me now with new products that they've read or heard about or you know, anything else to be trialled and um, but it's just, it's just the experience of trying to change a mindset that you know, is very much grounded in the operations to think [pause] bigger.*

***Llew:*** *And how important do you think that is for sustainable design?*

***Celia:*** *Oh extremely important, and I mean they um, you know probably now, whenever we are about to build a new building [pause] we have a big presentation and the the architects, the consultants, the engineers and everyone from the consultancies, they turn up and we'll have the [head] talk about um, you know the building and what we expect of the building from an [organisation] perspective, [name of person] will say something. I'll talk about the same building requirements and what we expect of them when it comes to sustainability and then the project manager will talk more about, you know, the actual process of, you know, the design and construct process and all that sort of stuff; whereas that's only happened in the last three months. Sustainability you know, has now taken a front seat. (p5)*

Either focusing on the physical product or the processes that produce the final product, this category is still focused on finding a solution within a given set of declared requirements.

### *5.3.2 Category 2: Sustainable Design is Reductionist Problem Solving*

> *Sustainable design is the process of identifying and solving a client's problem by making separate decisions that each decrease the associated environmental, social and economic impact. (n=4)*

The focus of this category is on the process of solving a client's problem. A final physical product is produced from the associated technical and human processes. In responding to an approach from a client, the sustainable design process identifies and defines the problem to produce a set of requirements for the solution. This problem identification and the subsequent development of requirements are *jointly constructed* by the client and the designer as part of the sustainable design process.

The process is an iterative one, but only one part of the problem identification or solution is considered at any one time. Each iteration of the design process produces an interim design solution, which is used to further define and explore the problem, and subsequently to refine the requirements of the solution. This process is represented by the feedback loop in Figure 9 (labelled Problem Identification), where each solution developed is fed back through the sustainable design process to further develop the solution.

A reductionist approach is taken to solve the problem. In this reductionist way, the problem is reduced to a set of smaller parts and solved independently of each other, without an awareness of how the parts influence each other. Each part is solved trying to help solve the overall problem while minimising the negative environmental, social and economic impacts from that individual part.

The process of identifying the client's problem rather than just accepting the client's initial requirements is described by Danny:

*We undertook I suppose to start, from a very broad point of view looking at what would the market want, what were our goals and and trying to set some specifications for our product ... If you try to work from an existing product, like modify a conventional vehicle to try and meet your requirements, essentially ... you're starting with a compromise um, and that you would never truly achieve the outcomes you'd desire and in fact often you'd end up going backwards. So clean sheet design was called for, clean sheet in the sense of er let's start from scratch; let's not make any assumptions really at all beyond saying it's a car; it's got four wheels; we've obviously got to meet certain Australian design rules, for example, so that it is actually registrable and saleable, but otherwise let's not make too many assumptions. (p2)*

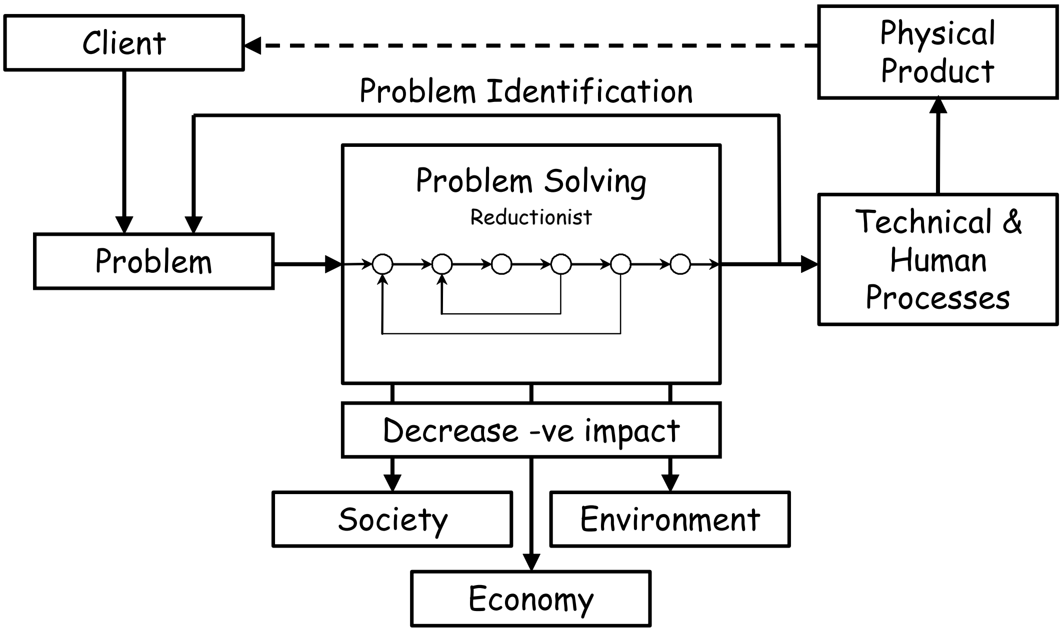


**Figure 9: Category 2 - Sustainable Design is Reductionist Problem Solving**

In addition to Danny, Zach emphasises the reductionist way that the elements of the problem are dealt with, where each decision is made to try to decrease its associated impacts independently:

*We broke it, the environmental issues down into um, oh, air, water, energy. They use a lot, where should we start, they use a lot of energy for compressed air um, so if it can make the compressors more efficient or simply use less compressed air. Often you can replace compressed air with non-compressed air if you're just blowing things, for example um, because they use a lot of compressed air to clean things after they've worked on them. They use energy in welding for aluminium boat building so welding equipment often is oversized. If it's old it just uses a lot of electricity so just replacing is a good thing to do. Then there's the standard office type things - lighting, air-conditioning. Manufacturers, fibreglass boat builders would use resins so they they might have heating and things like that so making that more more efficient. (p3)*

### 5.3.3 *Category 3: Sustainable Design is Holistic Problem Solving*

> *Sustainable design is the process of identifying and solving a client's problem holistically on a systems level, to increase the environmental, social and economic value of the solution. (n=2)*

The focus in this category is on the process of identifying and solving a client's problem *holistically* on a systems level. A final solution, in the form of a physical product and associated technical and human processes is produced to address the client's problem. A diagrammatic representation of this category is presented in Figure 10.

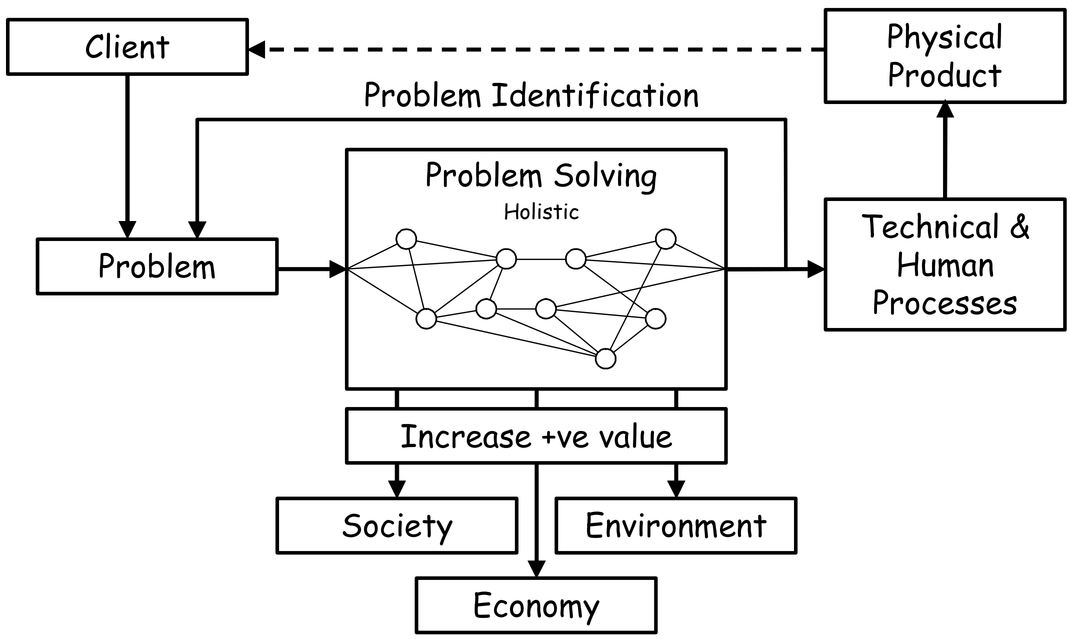


**Figure 10: Category 3 - Sustainable Design is System Problem Solving**

The holistic nature of the process is such that the client's whole problem is considered at all times, and not as a set of parts that are solved independently. The identification and solving of the problem are conducted concurrently with each other and with an understanding of how one influences the other. In solving the client's problem, each decision is made with an awareness of how that decision influences the other elements of the system. By taking a holistic approach, the solving of the client's problem is focused on trying to increase the environmental, social and economic value of the solution to the client, by considering all the decisions that are made together. Individual impacts are not considered in isolation, so the idea of value is used instead for the whole system. Accepting an alternative solution in one part of the system that has a greater negative environmental impact than other alternatives may enable the whole system to have less of an environmental impact overall.

The holistic nature of this category is discussed by Walter, who talks about challenging conventional mining operations by taking a holistic view of the client's problem:

> *There's been a project run by one of the [organisation] centres which is mine to mill, which is taking a more systems approach to a mining operation. What's tended to happen is the mine has tended to optimise its own sort of things from an economic basis and then the mill has tended to do its own thing and if you get them to talk to each other and focusing on energy in particular, what, people have concluded is that generally speaking it's more effective to use more explosive in the mine, break up rocks more finely and then consume less electrical energy in the mill in crusher cranes. All the studies they've done have tended to support that and all the studies they've done have tended to be done on the basis of economics - what's the best thing for us financially. But they have made the argument that environmentally, because we're consuming less power, it's better, but what people have not thought about is well if you're using more explosives, okay, we're using less electrical power but we're actually using more explosives. What are the environmental impacts that come with those additional explosives. How energy intensive is er, the manufacture of a tonne of ammonium nitrate and therefore is that claim that we're doing the right thing environmentally really right. It might not be; it might actually be worse. (p16)*

By looking at the problem of crushing the mined rock in a holistic way, the conventional thinking of using more explosives is called into question. Walter argues that this may in fact have a greater negative environmental impact, and that by looking at the system holistically, a greater positive environmental and economic value could be obtained.

### *5.3.4 Category 4: Sustainable Design is Social Network Problem Solving*

> *Sustainable design is the process of identifying and solving a client's problem, embedded within a wider societal context to increase the environmental, social and economic value of the solution to both the client and society. (n=5)*

The focus of this category is the framing of the client's problem within the larger network of problems facing society. A solution is developed by considering the client's problem as being embedded in a wider social context of problems. Considering this wider context brings with it a set of requirements and constraints that are included in the problem solving process as well. The intermediate outcomes of the problem solving process are fed back into further defining the problem. This may in turn reveal a different set of problems facing society than originally thought, which are then fed into the sustainable design process.

The identification and solving of the client's problem framed within the network of social problems is carried out holistically on a systems level. For each decision taken there is an awareness of how that decision influences the other elements of the system. How each decision that is taken affects the wider set of problems facing society is also recognised and is included in the decision making process. A diagram of this category can be seen in Figure 11.

The solution that is produced is done so to increase the positive environmental, social and economic value of the solution within both the smaller problem for the client and wider network of problems for society. The solution is still for the client, but is also developed to address the problems facing society that have been identified during the sustainable design process.

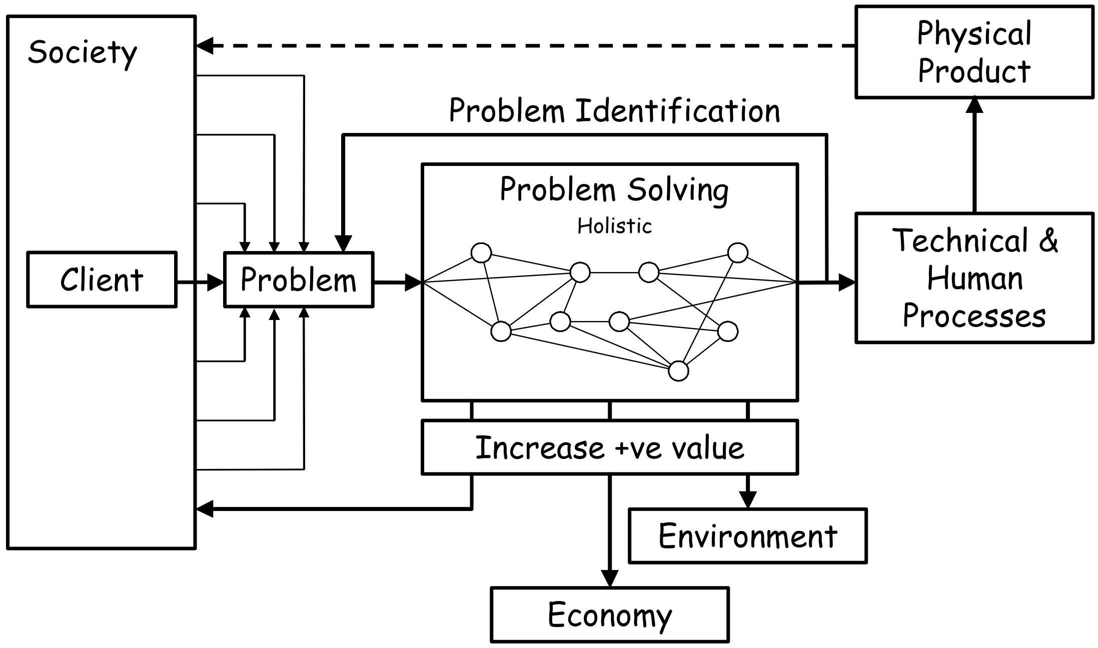


**Figure 11: Category 4 - Sustainable Design is Social Network Problem Solving**

The focus of this category as solving problems that are part of larger problems facing society is illustrated by Larry specifically in terms of water:

> *In terms of assessing whether an engineer understood and can practice, in a way that understands that what they're doing will change the way communities work, and in the past engineers have never done that, they've never asked the community whether they really want curbing and guttering, it's just a nice engineering practice to do it. Um, but of course a lot of people now are saying you know, "why do we collect all the water on the roads, and we put it all down the stormwater and shove it away, when we're such such a desperately dry continent?" You know, and that was a neat thing for engineers to do. If you go back and look at drains, stormwater drains designed in the late Forties, Fifties, Sixties, they're all concrete lined, very efficient. You know the, hydraulics is beautiful. But of course, we just losing all the water, 'get it out of here fast' [laugh] was the concept, um, where as now we put barriers and wetlands and retention basins, swales, and all these things … I think it's fairly critical to um, to get an acceptance by the community of the projects and why you doing them and to listen to concerns, as I say um, this is another example. I'm picking up [a] water bottle. [long pause] Did engineers ever ask the community if they wanted potable water piped to their house? No, it was a good engineering solution. Now people are running around, spending four or five dollars a litre to buy potable water and hosing their garden and washing their car with potable water, which is ridiculous. (p4)*

Larry goes on to emphasise the focus of this category on solving problems that are part of larger problems facing society, and the need to understand how the designs that are created impact the wider society:

> *I went through my four years of undergraduate training and, and design to me was just here's the problem, and you sit down and solve something. Whereas design is much more than that. It's [pause] systems thinking. It's bringing a whole lot of inputs to analysing [the problem]. [Pause] But then sustainable design takes it that step further and introduces to my mind the concept of a human issue … and a environmental issue. See it's [long pause] true triple bottom line applied to design and that's sustainable design. [Pause] And I think you must first have a basis in the philosophy of design and how design impacts on both you and the society that you designing for. (p15)*

This category focuses on solving a client's problem holistically, within a greater societal context.

### 5.3.5 Category 5: Sustainable Design is a Way of Life

> *Sustainable design is a way of approaching life where all the activities engaged in aim to increase the environmental, social and economic value of the outcome to both the individual and society. (n=6)*

The focus of this category is on sustainable design as a way of life that pervades all or most of the decisions the designer makes. In particular, sustainable design acts as a guiding belief or ethos for the way designers approach a broad range of aspects of their lives. There is no separation between the work done as a professional designer or as a person; they do not leave their personal beliefs at the door of the office in the morning. The core process of sustainable design is trying to facilitate this way of life.

The design problems to be solved may be provided by an external client or by the designer herself. There is a realisation, though, that not all of the problems faced can be solved to the level that is either required or wanted. This being the case, the designer attempts to increase the positive environmental, social and economic value of the solution as much as possible, for the client as well as for the wider society. A diagram of this category is presented in Figure 12.

The focus on sustainable design as a way of life is discussed by Amy, who argues that sustainable design should be treated as an integral part of life, and not separated out as 'practice':

> *I guess I don't like to just think of it as sustainable design. To me it's just it's part of life. It's not a separate thing that I can single out. That's how I like to think of it. I think a lot of how [pause] we're required to work, makes it into a separate thing, gives it a star rating, puts it in a category where it has to be judged, it has to be measured, it has to be costed, when it should just be an integral part, an indistinguishable part of life [long pause] if we're going to survive. (p9)*

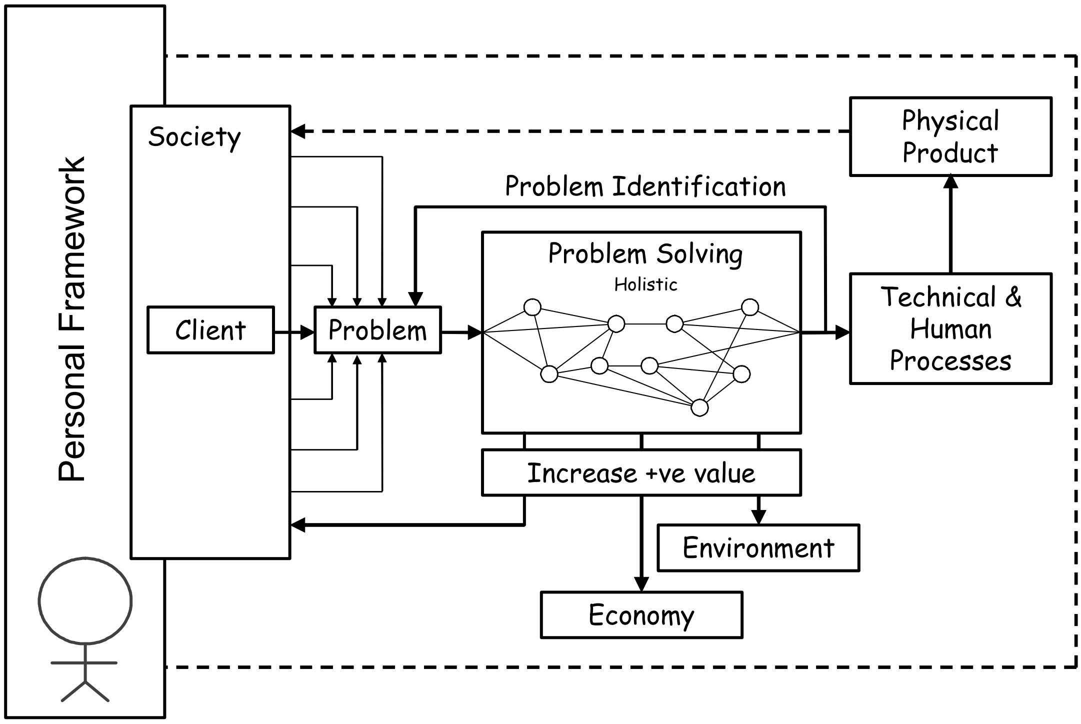


**Figure 12: Category 5 - Sustainable Design is a Way of Life**

Henry takes this point further, and tells of how he encourages others he works with to use sustainable design in their professional and personal lives:

> *I'm trying to show people that by taking on sustainability at work and at home, they can take control over global warming. [Pause] Hence I say 'Take sustainability into designs and change your designs, [then] take sustainability in design home. Pull out your ordinary light bulbs, put in compact fluorescents, put a bucket under your washing machine discharge and carry the water into the backyard. Open your doors and windows at night to cool down your home. Um, all those sorts of things, compost your food scraps. When you're designing at work [pause] look at the whole system. How can you optimise the the whole system [to] come up with better solutions?' I give people hope [pause] by basically saying 'Your children ultimately will inherit a better Earth.' (p15)*

By using sustainable design as a framework for both professional and personal activities, sustainable design moves from just a process and becomes a way of approaching life.

## 5.4 Relationships Between Categories of Description

The five categories of description presented in the previous section represent five qualitatively different ways of experiencing sustainable design among the twenty-two subjects interviewed in the study. There is a relationship between the categories in the form of a hierarchy, from less comprehensive to more comprehensive in terms of both the aspects the categories include and the linkages between these aspects. The hierarchy of the categories can be seen in Figure 13. It presents both similarities and variations between the categories of description of sustainable design.

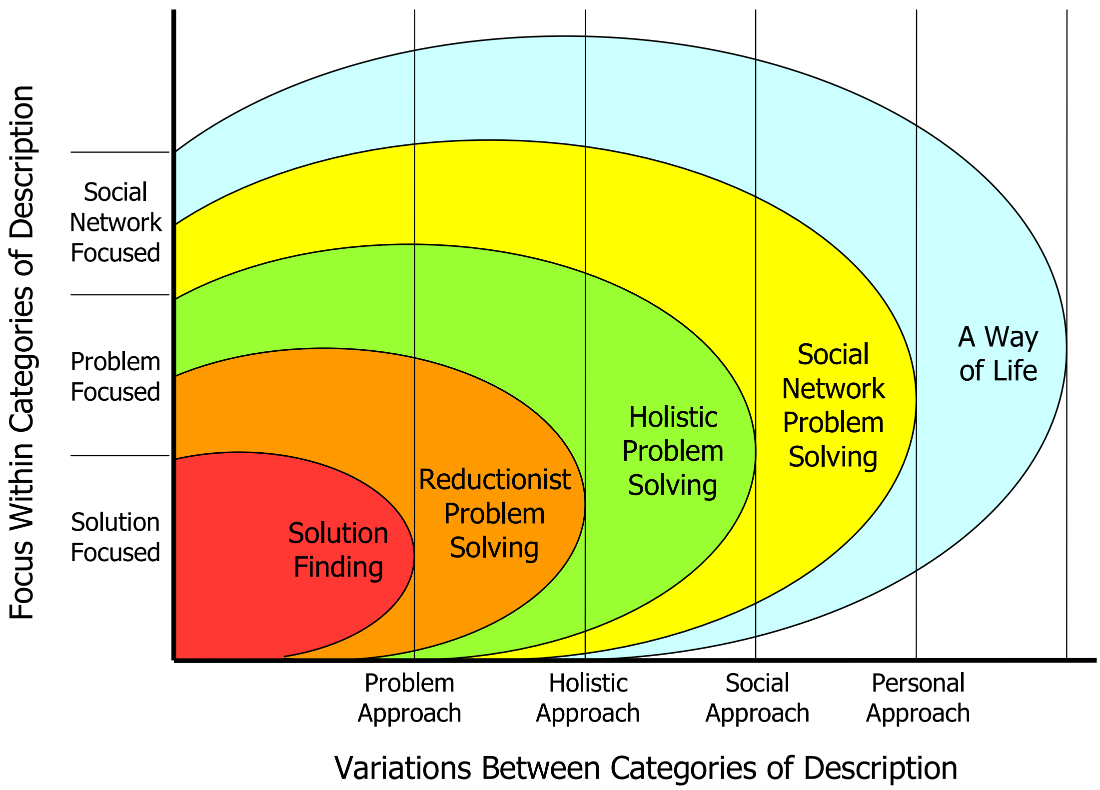


**Figure 13: Relationships between Categories of Description**[8]

The five categories have between them three different focuses; solution focused categories, problem focused categories and social network focused categories. As the categories become more comprehensive, the focus within the category broadens, effectively increasing the scope of the solution that can be found. The solution focused

[8] Note that this is not an example of the 'themes of expanding awareness' presented in some phenomenographic studies (Åkerlind, 2005a).

category is just looking for the solution within the client's declared requirements. A solution is found solely to fit with the requirements, as that is all that matters to the designer.

The problem focused categories widen the available scope of solutions by reconsidering the client's problem in collaboration with the client, and jointly determining the final requirements of the solution. This enables other possible solutions to be proposed that solve the client's problem, but that may not have been allowable within the initial client's requirements.

The social network focused categories take the focus on the problem a step further, but looking not just at the client's problem, but at the network of problems facing society that surround and influence the client's problem. The solutions that are found are done so within the broader framework of the social network.

The main variations between the five categories of description involve the approach the designer takes. While the focus within the category is also a point of variation, it shows more the similarities between categories than the differences. They are linked however, in that the approach the designer takes enables them to have a different focus within the category. The four different approaches that distinguish the different categories are a problem approach, a holistic approach, a social approach, and a personal approach.

The problem approach echoes the change from finding a solution to looking at the problem. The holistic approach is a move from making design decisions in a reductionist way to making them in a holistic way, with the focus still on the problem. The social approach echoes the move from looking just at the client's problem to looking at the client's problem within the larger network of social problems. Finally, the personal approach is the move from considering sustainable design problems externally, to seeing them on a personal level with the designer as a part of society. This results in sustainable design being seen as a way of life, as opposed to a way of designing, which is what the four previous categories refer to.

The specific relationships between the five categories of description in hierarchical order are as follows.

**Category 1 → Category 2**

Category 1 has a focus on producing a solution to a client's declared requirements, as already identified and determined by the client. The key variation between this category and category 2 is the move from accepting these declared requirements as is, to identifying, along with the client, what the requirements are from the client's problem. This identification process is one that involves both the client and the designer in jointly constructing the final set of requirements as the problem is explored and from the interim solutions that are produced. Starting with the problem enables the designer to develop different requirements than the client may offer. Using these may deliver a better solution overall to the client, or reduce the negative environmental, social or economic impacts of the solution *compared to if the original client's requirements were used*. Category 2 is thus more inclusive, as a solution is still found but to meet jointly constructed requirements.

The variation between categories 1 and 2, from solution to problem, is demonstrated by the following quote from Uma. While she explains having to work within the client's declared requirements, she can see that collaborating with the client to determine what their problem is and designing a solution from that would have achieved a better solution. In this case, Uma relates an experience she had with the designs of a housing development:

> *[The housing plan is] submitted to council and council either approves the plan er, in which case [the client] is required to implement whatever they've said they will do in the plan. Or it's rejected on the basis of they haven't done enough, they haven't demonstrated that they are really trying to make sure they are not having a big impact on the water ways. In which case it comes back to us and we sort of look at it and go aw geez this is hard because usually [the client] comes to us and they've done the lot layout, they've decided exactly what they want. There might not be a square inch of space for us to do anything and they say fix it, you know, we want to get this passed. Whereas if they approached us before hand, we could actually work with them, and it might mean that they lose half a lot, but the there is a mentality there that needs to change. (p3)*

By jointly identifying the problem, they may have had a much better outcome with less of an environmental impact. Instead the solution that was found within the declared requirements was not as good as it could have been.

**Category 2 → Category 3**

Category 2 and 3 both focus on the problem as the core of sustainable design. The key variation between the categories is how this problem is handled. Category 2, reductionist problem solving, looks at the solving of the problem as a series of smaller parts, where one is solved after another. Each part of the problem is solved separately without reference to the influences the parts have on each other, to decrease the environmental, social and economic impacts of each part. Category 3 looks at the problem solving process holistically, where the problem cannot be solved by reducing it into separate parts and solving them independently. As a result, the problem must be solved holistically as a whole system, with an understanding of how the consequences of each decision impact the other elements of the system. Category 3 is more inclusive than category 2 in the way that it approaches the problem solving process and is thus higher in the hierarchy.

This holistic approach also carries with it another variation between the two categories; the move from trying to decrease the negative impacts associated with the product, to trying to increase the positive environmental, social and economic value of the product. Minimising negative impacts can be straightforward when making single decisions, as one option usually has less of an impact than others. Trying to minimise the impacts associated with multiple decisions that have an impact on each other at the same time becomes a more complicated problem. Making a particular decision may minimise that decision's associated negative environmental impacts, but may impact other elements in an unforseen way, increasing the negative social impact in another part of the system. In category 3, the aim is to increase the overall positive value from all the decisions made. With this approach, a larger negative environmental impact may be acceptable in a certain part, because it would mean that overall, the positive environmental value of the system is greater.

As an illustration of this trade off aspect of category 3, Walter discussed part of a mining operation as holistic problem solving, where decisions need to be made with an understanding of how all the elements impact each other in order to increase the value of the whole system. In this case, a student in a class Walter is teaching proposes having a larger negative economic impact than is the norm, in order to have a greater positive social value overall:

*It’s always that question with mines, how long they're going. And when they close there's a number of very serious issues they're going to have to face up to about the local communities and health facilities and all those things. ... One of the questions that a student asked, that this particular student had was [pause] have they ever considered actually slowing down production, so only mine at half the rate and make it go longer and give yourself more time to adjust and [aim for] some of those sustainable outcomes.*

*And if you think about that in terms of the broader mining industry um, it’s actually quite a good question. When we've got an ore-body, what are the factors we consider when we consider the production rate and how long are we going to exploit that for um, in terms of the social impacts? Now if it’s in the middle of nowhere, because many mines in Australia are, and you haven't got a local community, then it may not be an issue. But if you try to do something with some regional outcomes, then instead of going in there for ten or twelve years, which is quite a common mine life for a small goldmine these days, is there an option to do it more slowly. That flies in the face of all the engineering thinking, which is all about economies of scale and doing things more quickly, and everyone’s talking about expansions, because on the financial scale that’s a better outcome. (p15)*

**Category 3 → Category 4**

The variation between category 3, Holistic Problem Solving and category 4, Social Network Problem Solving, is the move from just looking at a client’s problem to looking at a client’s problem as part of a network of wider problems facing society. In category 3 there is not an awareness of the larger dimensions outside of a client’s problem, but it is still solved holistically to increase the positive value to society. Category 4 includes the greater awareness that a client’s problem is a subset of a larger network of societal problems, and tries to solve it to increase the solution’s positive value to both the client as well as the wider society. Category 4 is therefore more inclusive than category 3 in terms of the range of problems that are considered.

The following two quotes illustrate the difference between category 3 and category 4. As an example of category 3, Walter discussed a problem the client had with material usage in a process with a focus on the client’s problem only, particularly the issue of waste. Waste though is a problem that the wider society is facing also, but these problems are not included in the consideration of the client’s problem.

***Walter:*** *We had a theme on general materials use, so just their inputs in terms of what materials were they bringing on site [cough], how efficiently they were using them, what sort of yield they might be getting or how much of that particular product might be wasted um, including the products they were producing. They had a bit of an issue with ammonium nitrate dust and how that was managed at the end of their process, so getting spilt.*

***Llew:*** *And why do you think that um, why was that important?*

***Walter:*** *Well it, it's important for the company if you're talking about a product, the more they can get into the final product and not damaged or thrown away then obviously financially they're better off then. It also means that the associated um, impacts associated with producing more tonne of that product, not only do you get more money for producing a tonne but you also reduce them as impacts, incrementally, but still reducing. (p6)*

Simon, on the other hand, discussed the problem of supplying water to households but saw it as part of a larger network of problems facing the wider society, namely the alienation from what is involved in delivering everyday services such as water in the middle of a drought, and the impact that has on the environment, as an example of category 4:

*When you take water from the tap, um, most people don't know where it comes from, but it's rained somewhere, and it's been gathered in a dam, its flowed in a stream, its come to a place, its been treated, its gone through pipes, and its come out of a tap somewhere. Um, there's a whole pile of things happened. So my sense of alienation er, is is about um the overwhelming majority of people, including the leaders of the country, the leaders of our societies, not understanding or knowing or thinking about what's involved in the life that we lead. So we focus on topical, sometimes trivial um, often passing fads, fashions er, issues they call them, you know what's the issue or issues, the issue itself is a construction. [pause] And at the moment the the very fact that, you know, we have a water er, scarcity here in South-East Queensland, um, people are responsive to water restrictions, um, but most probably haven't thought about why we are in those water restrictions. It's largely explained in terms of drought, but [pause] as equally important as the drought is the the wanton waste of the resource and the way we use it. There could be a lot more water in that dam right at this moment had this, had this community not wasted as much as it has in the past five years, when the dam was last full. (p10)*

**Category 4 → Category 5**

The key variation between category 4, Social Network Problem Solving and category 5, A Way of Life, is the change from seeing sustainable design as something that is done as a designer, to something that is done as a person for the greater good of society. Moreover, sustainable design becomes a framework for approaching aspects of life. Category 5 is thus more inclusive than category 4, as it incorporates sustainable design in a professional context as well as a personal context.

In category 5, there is no separation between what is done as a designer and what is done as a person, as Natalie describes:

> *For me, I do try to integrate, keep that integrated, that my personal life and my um, professional life are actually one and the same. Like I am one person, I am not two, you know, like a working person and a private person and so I try to keep that sort of integrity across er, across both of them. (p4)*

This is contrasted by Simon as an illustration of category 4, in not seeing sustainable design as a way of life. He is happy to apply sustainable design principles in his work, but will still buy products for his personal life that he knows and admits have negative environmental and social impacts, in this case his leather lounge:

> *I use the example in fact of my er nine hundred and ninety-nine dollar, five seater leather lounge at home that we bought a couple of weeks ago. Um it's nine hundred and ninety-nine dollars to me because um the Chinese do not protect their environment, I can safely assume that the um er harmful materials used in the treatment of the leather to make the thing were not internalised but now probably now in the Yangtze, um and that the Chinese labourers who were enjoying by Chinese standards probably six dollars a day or whatever to, to make the thing are relatively well, by third world standards, well employed but by our standards of course um they provided me a subsidy because I don't, I get a lot more than six dollars an hour. So if you're going to look at sustainable design, you you've got to look well beyond the engineering implications [pause] and think about it in that in that context. p7*

The five categories of description and the relationships between them form the basis of the results of this thesis. Before the implications of these qualitatively different experiences of sustainable design can be discussed, it is worthwhile looking at the distribution of individuals across the five categories identified.

## 5.5 Distribution Across Categories

The categories of description of sustainable design were developed looking at qualitative variations between interview transcripts. As such, each transcript was classified into a category during the analysis process. The distribution of the twenty-two transcripts in each of the five categories of description ranged from two to six. Thus I argue that I was successful in obtaining the variation I set out to.

It must be remembered however that this distribution is based on only the experiences discussed in the interviews. As such, the placement of the transcripts into the five categories only relates to the transcripts, and not to the subjects themselves. Just because the subjects related their experiences from one particular category of description does not mean that they are always in that category.

## 5.6 Conclusion

What then do the categories of description, the relationships between the categories and the distribution across the categories mean for both the practice and education of sustainable design? This question will be explored in Chapter 6 which discusses the impacts of the results for improving sustainable design practice, and improving the education of future engineers about sustainable design.

# 6 IMPLICATIONS FOR ENGINEERING PRACTICE AND EDUCATION

## 6.1 Introduction

In the preceding five chapters, this thesis has developed an argument for the inclusion of differing ways of experiencing sustainable design within engineering professional development. This chapter discusses the contribution this thesis makes, both in a theoretical and methodological sense. Developing practitioners' and students' ways of experiencing the practice of sustainable design is a vital step to meet the challenges outlined in Chapter 1. This chapter discusses the implications for improving the practice of sustainable design (Section 6.2) and improving the formal education of sustainable design for both engineering students and experienced engineers (Section 6.3). The wider use of phenomenography in engineering research is a major methodological contribution and is discussed in Section 6.4. Future investigations are also proposed in Section 6.5 to extend the findings of this research.

The generalisability of the results needs to be discussed before the specific implications of the study are presented. In Section 3.5.3, I argued that conventional notions of generalisability are not valid for a phenomenographic investigation. Instead, it is argued that the range of experiences in the sample is generalisable to a similar group of subjects. In this study, the ways of experiencing identified ranged from solution finding within a specific set of declared requirements, to sustainable design being a way of life. Another group of practitioners with similar characteristics to the subjects in this study (see Table 5) will most likely have the same range of experiences identified.

## 6.2 Implications for the Current Practice of Sustainable Design

One of the main contributions this thesis makes is to enhance the current understanding of engineering practice. It does this by highlighting an aspect of practice previously ignored in engineering. This aspect, the ways practitioners *experience the practice* of sustainable design, has implications for the current practice of sustainable design. It calls into question the traditional view of competent practice being constituted by specific attributes, in line with what Sandberg (2000) argues. Further, more comprehensive ways of experiencing sustainable design, it is argued, will help designers to address the challenges they will face in the future.

There are three levels for which this thesis has implications for engineering practice, on an individual, design team and organisational level. Each of these is discussed in this section, including the changes suggested to current practice.

### *6.2.1 Individual Practice Level*

The categories of description presented in Chapter 5 have many implications for individual practitioners. In particular, the ways that practitioners experience sustainable design have been described in terms of how they act in practice, and what they regard as sustainable design within their work. A similar study was conducted examining the experiences of engine optimisers at Volvo (Sandberg, 2000). It found three different ways that workers had experienced engine optimisation: optimising separate qualities; optimising interacting qualities; and optimising from the customers' perspective. The first two of these categories match well with categories 2 and 3 identified in this study, those of reductionist and holistic problem solving respectively. Like the Sandberg study, in this thesis practitioners' ways of experiencing is interrelated to their way of acting in practice.

The subjects were asked in the interviews if there was one experience that changed their understanding of sustainable design. Not many practitioners could single one particular experience out. Instead many described it as a gradual change over time. Thus it could be argued that the development of their way of experiencing sustainable design was more a process of refining their existing understandings of practice, rather than there being a sudden transformation to a more complex way of viewing practice. This agrees with what Dall'Alba and Sandberg (2006) argue in their critique of stage models of professional practice. This also has implications for further understanding practice.

The relationships between the categories of description have many implications for improving the practice of sustainable design as follows:

**Category 1 → Category 2**

The relationship between seeing sustainable design as finding a solution as opposed to solving a problem is an important one for improving the practice of sustainable design. There is a key difference between these ideas. In finding a solution to a set of declared requirements, the requirements act as 'pegs in the sand', by defining a boundary within which the solution can be located. The solution is then found within this limited space (see Figure 14). Solving the client's problem however involves the evolving development of the requirements boundary, in collaboration with the client. While the client's idea of the problem may start small, the evolution process allows the designer to explore possible solution spaces that would not be allowed in solution finding.

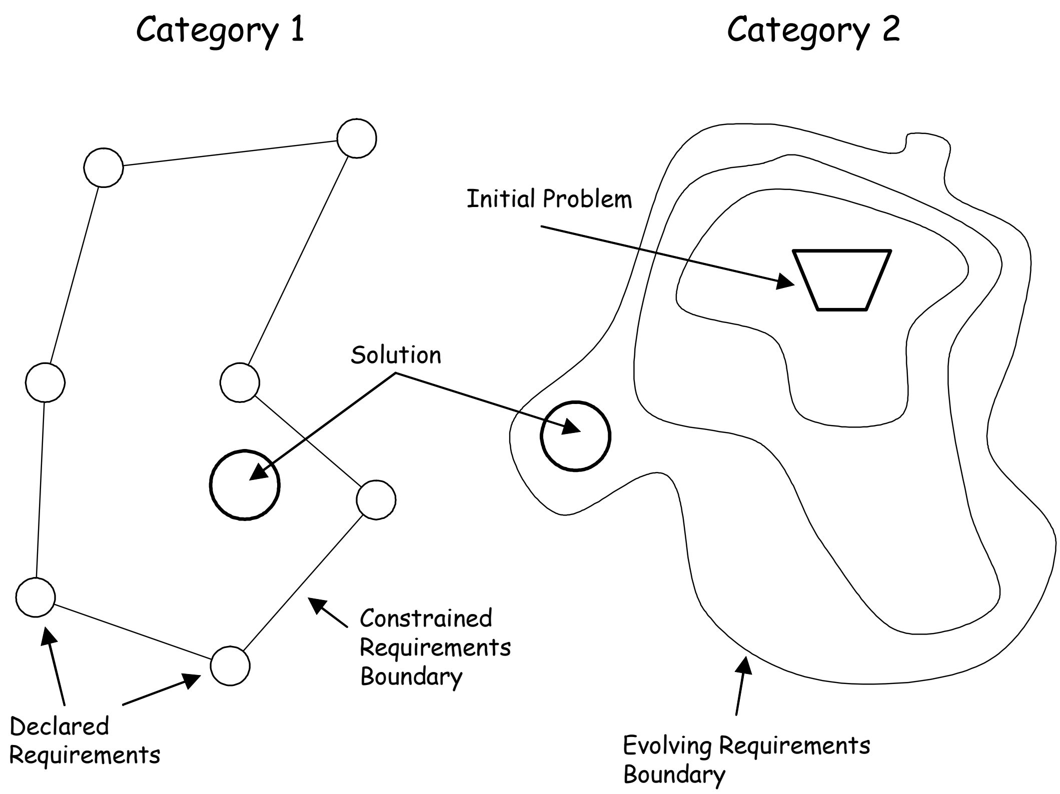


**Figure 14: Comparison of Solution Finding and Problem Solving**

Another interesting implication of the first two categories of description identified is that they both could be thought of as ‘good’ traditional design. It is argued that Category 1 can be thought of as traditional design, with the addition of ‘decreasing the environmental and social impacts’. In traditional design, a client has a set of declared requirements, and a solution is found, in the form of a product and processes, that decreases the associated costs. Category 2 can be thought of as ‘insert traditional design process here’ in the problem solving box, as most traditional engineering design tends to be reductionist in nature (see Figure 9).

**Category 2 → Category 3**

The major implication of the relationship between Category 2 and Category 3 is the focus on the co-evolution of problem and solution spaces. In both categories, these are developed together, as this helps in exploring the problem solving space seen in Figure 14 (Dorst & Cross, 2001; Maher et al., 1996). It also allows for more creative designs to be pursued. Traditional systems engineering however, used for large complex designs, is not flexible enough to cope with this co-development, even when it is tailored (see, for example Mann & Radcliffe, 2003a; 2003b). This suggests the need for a holistic problem solving approach, looking at the interconnections between elements of a design (Category 3).

Another interesting aspect of this relationship between Category 2 and 3 is the change from minimising negative impacts to increasing positive value. This is similar to the change from eco-efficiency to eco-effectiveness discussed in Section 2.3.1 and the ecosystem principle. Once a holistic view is adopted, individual decisions are no longer easy to make. In a holistic sense, a decision to lower the negative environmental impact of an element of the design may, for example, increase the negative social impact on another part of the system. Thus the shift in Category 3 to looking at the overarching positive value of the design.

Holistic problem solving is also linked to the idea of service and flow from Natural Capitalism (Hawken et al., 1999) and the human vitality principle (McLennan, 2004). Taking a holistic approach to solving problems allows for the shift to a service and flow economy.

**Category 3 → Category 4**

The relationships between Category 3 and 4 point to the need to focus on the wider social and environmental problems surrounding the client's problem. Even though Category 4 only included the larger societal context, it is argued that the environmental context also needs to be made explicit. This relationship also demonstrates the need to look at the impacts of any proposed solution to the environment and society, closing the feedback loop shown in Figure 11.

The idea of increasing social value is linked to the second principle of sustainable design identified in Section 2.3.2, that of the human vitality principle. This principle is also highly relevant to category 5 when spiritual aspects are included.

Category 4 can also be seen as incorporating the waste equals food concept from the seven generations principle (McLennan, 2004) identified in section 2.3.2. For this to happen effectively, I argue that operating at least at category 4 is essential. Not only is a holistic view required to look outside the confines of a particular company or system, but there needs to be an awareness of the issues within a wider social and environmental context to understand how the wastes from one system can become food for another system. An example of this is the Kwinana Industries Council (2006), which is incorporating the idea of By-Product Synergy, or waste equals food, to an entire industrial area. Local industries have come together and identified the inputs (food) and waste outputs from their systems and tried to see where the wastes from one industry can be used as a food for another industry.

**Category 4 → Category 5**

The main implication of the relationship between Categories 4 and 5 is that for some, sustainable design is something they do as a professional, whereas for others, it is a way of life. From the discussion of biomimicry (Benyus, 2002) in Section 2.3.2, seeing nature as a model could be part of Category 4, whereas seeing nature as a mentor is within Category 5. Further, the four steps to achieving sustainability advocated by Benyus (2002) is also part of taking a category 5 approach. This is because quieting human cleverness, listening to nature, echoing nature and protecting the wellspring of good ideas through stewardship all require a deeper conviction to sustainability and sustainable design as a way of life.

Ultimately many of the principles of sustainability and sustainable design suggest that Category 5 is the ultimate approach, and the one that needs to be adopted to have a sustainable future.

### *6.2.2 Design Team Level*

At a design team level, the major implication of this study is the realisation that different designers and the other stakeholders involved will have different ways of experiencing sustainable design. These will influence the thoughts and actions of individuals within the group. This being the case, when working in a group situation on sustainable design, it is important to firstly try to identify what the different group members' ways of experiencing sustainable design are. This will help address the disagreements discussed in Section 2.2.2, which often arise due to peoples' different understandings of the same situation.

It must be remembered however that everyone operates or performs tasks at different categories depending on the situation and the wider context. Some projects require designers to only operate at less comprehensive ways. For example, a particular design task may have a set of declared requirements that must be met (Category 1). However, even though designers may have to operate at less comprehensive ways of experiencing, they may be doing so from their more comprehensive way of experiencing. So if a designer's way of experiencing is at Category 4, social network problem solving, at a particular time, and they are confronted with a design task to find a solution (Category 1), they will do so within their Category 4 framework.

On the other hand, certain contexts may actually make practitioners regress to less comprehensive ways of experiencing. For example, in their office environment they may have a Category 4 way of experiencing but in visiting a new site and talking to the client, they may revert back to a Category 1 or 2. Different contexts determine which framework practitioners use.

### *6.2.3 Organisational Level*

Any workplace wanting to integrate sustainable design into their organisation should encourage practitioners to critically reflect on their current practice, and how integrating sustainable design into their work can develop their way of experiencing that practice (Dall'Alba & Sandberg, 2006). A necessary feature of enhancing practitioners' ways of experiencing practice through reflection is enabling them to become aware of their current ways of experiencing. Further, they need to be made aware of other ways of experiencing practice that exist. It is easier for change to take place if practitioners are aware of both where they are and where they could be in their experiencing of sustainable design.

Different people in a company will have different ways of experiencing sustainable design. The same issues that apply to a design team apply to a whole organisation. People in the organisation need to be aware that others may have a different way of experiencing sustainable design that will inform the way they act in practice. This knowledge can be used by people with more comprehensive ways of experiencing to constantly challenge others to transform their ways of experiencing sustainable design.

More generally in an organisation, "there is scope for critically reflecting on the function of the organization or the service it provides in a way that calls into question, and extends, experiencing of practice" (Dall'Alba & Sandberg, 2006, p404).

Further, I argue that an organisation as a whole develops, in effect, its own 'way of experiencing' sustainable design when compared to other organisations. It does this through the internal practices it uses, the culture and values it instils in its staff, the experiences of the staff that work for it, and the projects it chooses to work on. Different organisations act differently when confronted with sustainable design issues, hinting that these different ways of experiencing sustainable design at an organisational level may exist, though this is yet to be investigated.

This thesis also has implications for organisation change toward more sustainable practices. As McLennan (2004) argues:

> *Organizational change from a conventional company to a green company or institution requires changing the mindsets and patterns of numerous people, all at different points in their overall journey and at different levels of interest in sustainable design.*

AtKisson proposes an amoeba model for organisational change and innovation diffusion, seen in Figure 15. As AtKisson (2000b) proposes:

> *Picture human culture - or any particular subculture of it - as a giant amoeba. Individuals are like the molecules that make up that amoeba. They move around, playing different roles at different times in different parts of the organism. An amoeba moves by sticking out a small pseudopod ("false foot") into new territory. The rest of the organism inevitably comes sloshing along behind. Because of this sloshing effect, the nucleus or center of the amoeba arrives a bit late on the scene compared to the majority of the organism's molecules.*
>
> *This review of basic biology provides an elementary model for how cultures change. The sloshing of the nucleus is akin to the phenomenon of the lagging center - the tendency for the mainstream (and especially the power structures) to be far from the forefront of cultural advance. The pseudopod is the realm of the innovator and the change agent. Not every pseudopod rules the day; in a culture, there may be antagonistic forces trying to push another pseudopod out in the opposite direction. Again, the message for the would-be world-changer (or organization-changer) is clear: the trick is to have a winning pseudopod. But, as in biology, a pseudopod that leads the whole amoeba on to more nourishment and growth*

*opportunities is far better than one that succeeds in leading the whole into the microscopic equivalent of a wasteland.*

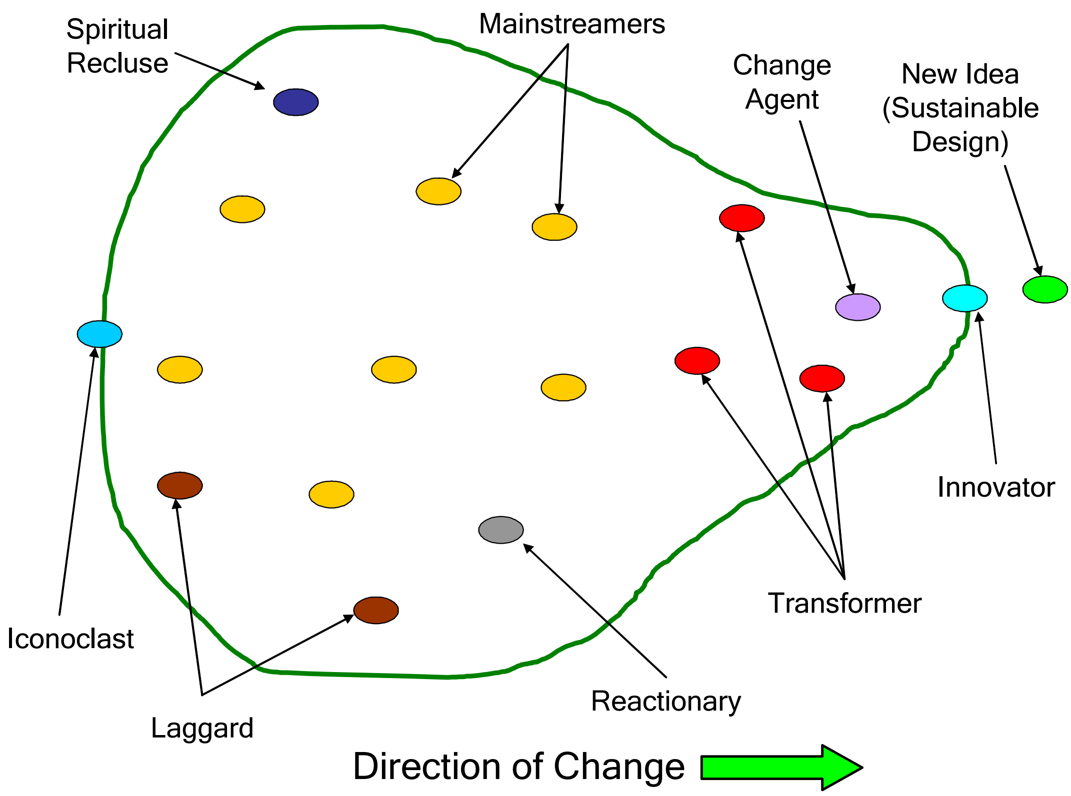


**Figure 15: Amoeba Model of Cultural Change**[9]

Within the model, there are many players, each acting to either move the organisation toward sustainable design, or resist the move. It is important to note that in reality, everyone plays the roles identified by AtKisson in different contexts. For example, someone may be an Innovator when it comes to new gadgets, a Mainstreamer when it comes to Computer Aided Design packages, and a Reactionary when it comes to multidisciplinarity. There are a few roles of particular interest to changing organisations.

According to the model, all innovations within an organisation start with an Innovator, a person or group of people who invent, discover or initiate a new idea. These people are on the boundary of the organisation, constantly looking out for new ideas to incorporate into the organisation. As these people are on the boundary, they find it hard to diffuse the new innovation they find through the organisation. They need Change Agents.

[9] Adapted from AtKisson (2000)

Change Agents are the people that actively promote new ideas through an organisation. They are the innovation marketers, those people that sell the new idea to the rest of the organisation. “Change Agents understand that convincing people to try something new is more art than science, and depends more on communication skills than (merely) compelling evidence.” (AtKisson, 2000a, p182). Change Agents operate between the ‘lofty’ ideas of the innovators, and the people ‘on the ground’, focusing on the benefits of the new idea. For an innovation of be adopted and change to happen, the difference in perceived value between the old and new systems needs to be greater than the perceived cost of the change (AtKisson, 2000a). The idea is similar to Schein’s (1999) notion that for change to happen, the survival anxiety has to be higher than the learning anxiety. There are three basic strategies for motivating transformation that Change Agents use (AtKisson, 2000a):

- Promote the new – increase the perceived value of the new system or idea;
- Critique the old – decrease the perceived value of the old by attacking it, either subtly or openly;
- Facilitate the switch – reduce the perceived cost of making a change. This is the most important but often least obvious strategy for change.

The first mainstream people in an organisation that change toward the new idea are called Transformers. These people are typically open to new ideas and are the forward thinkers in an organisation. They are the group of people that start to shift the Mainstreamers, the majority of people in an organisation. The Transformers may change the new idea, making it less radical or easier to use in practice in order to bring the Mainstreamers along (AtKisson, 2000a).

Other people in an organisation include Laggards; Mainstreamers who generally don’t like change and will generally only change under pressure from the majority of Mainstreamers. Further, Reactionaries are those people that actively resist change, and who have a vested interested in maintaining the ‘status quo’. These people change very late, and often only if it is unavoidable. Iconoclasts are the critics of maintaining the status quo, so “while the Innovator pulls the amoeba from in front, the Iconoclast kicks it from behind” (AtKisson, 2000b, p4).

Finally, AtKisson identifies the Spiritual Recluses, who are withdrawn (either actually or metaphorically) from the mainstream, and who are more preoccupied with eternal truths than reality. These people often provide inspiration for the Innovators, Change Agents and the Iconoclasts.

Viewing change in an organisation in this way has implications for adopting sustainable design. Firstly, the categories of description identified in this study offer a way of understanding why different people will have different roles for adopting a change to sustainable design within a company. I argue that those people who are Innovators and Spiritual Recluses most probably experience sustainable design consistent with Category 5, as a way of life. These people are committed to incorporating sustainable design because they believe that it is essential, that it is a way of life.

Change Agents and Transformers then may experience sustainable design as Category 4, social network problem solving, or Category 3, holistic problem solving. This will depend whether they are focused just within the organisation or consider the wider societal and environmental context. Mainstreamers then are likely to be Category 1 or 2, solution finding or reductionist problem solving. The purpose of the Change Agents and Transformers is to then move the Mainstreamers to more comprehensive ways of experiencing sustainable design.

Finally, other groups such as the Reactionaries do not fit within a category identified in this study. All subjects interviewed in this thesis had experiences with sustainable design and many of them were recognised as leaders in the field. As such, no one discussed experiences that were negative of sustainable design or discussed opposing change. However I argue that if a study was conducted within a typical engineering company, these negative ways of experiencing sustainable design may become evident.

The other implication for change that this model indicates is that if an organisation is committed to moving to incorporating sustainable design, it must encourage the good and remove the bad. That is to say, it must identify the Innovators, the Change Agents and the Transformers and encourage them, while at the same time discouraging the Reactionaries within the organisation.

Finally, McDonough & Braungart (2002) propose five guiding principles for change to sustainable design:

- Signal your intention – Commit to a new paradigm rather than just improving the old. Signals need to come from the top down to give permission to company, but the signals need to be based on healthy principles, changing not only the designs but the values of the designers.
- Restore – Aim for 'good' growth and development, not just economic growth. Aim also for designs to have a restorative effect and an increased value to all, rather than just trying to minimise their harmful impacts.
- Be ready to innovate further – No matter how good your design is, there are always ways of improving it. Look for signals outside the company, from the community, the environment and the world at large.
- Understand and prepare for the learning curve – Realise that for a company to embrace sustainable design, changes will need to be made. "If all of your resources are tied up in basic operations, there won't be anything extra to allow for innovation [and change]" (McDonough & Braungart, 2002, p185).
- Exert intergenerational responsibility – Consider not only the current generation in design, but what implications may exist for future generations.

## 6.3 Implications for the Education of Engineers about Sustainable Design

Another main contribution of this thesis is in highlighting the need to change the way professional development in engineering is understood in practice, both for students at university and professionals in the workplace[10]. This change involves developing students' and practitioners' embodied ways of experiencing sustainable design practice, along with their engineering skills, to form their professional way-of-being (see Figure 2). Developing this professional way-of-being will allow students and professionals to engage in practice as competent professionals (Dall'Alba, 2004; Dall'Alba & Sandberg, 1996). It will also enable them to deal with the "complexities, ambiguities, and dynamic

[10] From this point on for the rest of the chapter, 'students' refer to both students at university and professionals undergoing professional development.

change inherent in professional practice" (Dall'Alba & Sandberg, 2006, p401), as how people understand practice is central to how they perform in that practice (Dall'Alba, 2004; Sandberg, 1994; 2000). Seeing professional development in this way has implications for the organisation of future engineering professional development efforts. In particular, the implications are for the focus of learning, curriculum design and the design of learning environments, both at university and for professionals undergoing professional development.

**Focus of Learning**

There needs to be a shift away from the transfer of knowledge, skills, attitudes and values, to developing a professional way-of-being, incorporating both engineering skills development, such as problem solving or design, and a way of experiencing practice. As discussed in Section 2.4.3, providing students with more and more decontextualised knowledge, skills, attitudes and values, will mean they will incorporate these into their current ways of experiencing practice. This also gives rise to a gap between the ways they deal with 'clear cut' problems presented at university, and the 'messy' problems of professional practice. "Knowledge and skills must become embedded within the understanding of professional practice being formed" (Dall'Alba, 2004, p689). Engineering education requires a paradigm shift to developing this integrated professional way-of-being, rather than learning content decontextualised from practice.

For example, the current way of teaching engineers about technical communication in the US is through a separate course, usually taught by an academic from another faculty (Reave, 2004). However it is argued that "such courses… are of little use and in fact there is a considerable risk of students ending up weaker in areas they were supposed to become better at" (Bowden & Marton, 1998). This is because what is learnt within a course is just as important as how it is learnt. Thus courses that separate, for instance, technical communication from learning about the practice of engineering do not develop the students understanding of practice.

Further evidence for the need to develop a way of experiencing sustainable design practice was put forward by Fiona in her interview:

*The there was a real recognition that kids are taught how to construct water tanks how to construct solar panels… as a practical solution to solving some of our water sustainability issues or our you know, increasing energy efficiency but they had no understanding of the theoretical component behind that so why are they building water tank was never taught the idea of water conservation, the idea that Australia's a dry continent. There's no understanding about climate change and and and energy consumption. (p3)*

*I think it's really important that education really starts to contextualise content and um, teach students that it's ok to have um, er a moral and ethical understanding of yourself and your sense of place, not to tell them what it should be but to say that you know you need to start to value certain things and those values need to be translated into your practice and um, one then needs to reinforce the other… so that you're able to make proper informed decisions rather than just regurgitating this theory or this for formula and then that you know means you've got a bridge but where is that bridge being built and why is it being built and you know those sorts of things. (p5)*

The more comprehensive ways of experiencing sustainable design identified in Chapter 5 will enable students to deal more effectively in practice. If the five categories together represent the range of experiences of sustainable design in practice, which way of experiencing the practice do we want to develop within students? I argue that developing more comprehensive ways of experiencing sustainable design within students will enable them to deal with the complex, 'messy' problems many will face as engineers in the future. Thus, we should aim to develop more comprehensive ways of experiencing sustainable design within students. It must be remembered however that this development is not a stepwise movement between ways of experiencing practice, but a continuum. The more comprehensive ways of experiencing practice need to become the basis of structuring engineering programs.

Another implication for the education and professional development of engineers about sustainable design is the need to constantly monitor how sustainable design is experienced by all, including students, academics and professionals. This information is a vital input into the design and continual improvement of educational curricula, learning environments and assessment (Dall'Alba & Sandberg, 2006). Thus changes in ways of experiencing, especially in engineering practice, need to be captured and integrated, and should become the focus of learning in educational institutions.

### Curriculum Design

An implication for curriculum design is that experiences need to be offered to enable students to develop their own way of experiencing professional practice. Opportunities need to be given to students throughout the curriculum to question and extend their current way of experiencing sustainable design practice and develop skills. One way of approaching this is to expose students to the ways of experiencing we want them to develop (Bruce et al., 2004). For example, exposing students to Category 3, holistic problem solving, may entail posing a problem that requires students to look at the problem in a holistic way, rather than in a reductionist way.

This constant focus on developing experiences of practice needs to be maintained throughout the curriculum, as argued by Dall'Alba & Sandberg (2006). It is also important that this focus is made explicit to the students involved. It is unlikely that students' ways of experiencing practice are transformed as a by-product of a course or program that does not have this focus throughout. Further, studies show that elements outside the formal curriculum play an important role in students' learning and development as professionals (Walther & Radcliffe, 2006b). This notion needs to be considered in the design of future engineering curricula.

### Design of Learning Environments

An implication for the design of learning environments in which curricular are situated is the need to actively engage students in learning processes, encourage students to support and challenge each other's development, and require students to be reflective about what they are doing (Dall'Alba & Sandberg, 2006). Recent educational research has shown how active learning processes are beneficial to student learning (see, for example Ramsden, 2003). Simply giving the students the 'right' way of experiencing cannot work, but must involve an active interplay between old and new ways. Further, these learning environments need to reflect the variation that is present in practice. The focus needs to be also on the students learning together: "we can use discussion and interaction between students to expose them to the meaning which the course content has for other students, and to explore and extend their own ideas through interaction with, and challenges from, others" (Dall'Alba, 1993, p311).

Education systems also need to take account of the external experiences of their students, in terms of sustainable design and engineering in general (Walther & Radcliffe, 2006b). Studies have shown that students often come into professional programs with different ways of experiencing practice already, and curricula need be developed to recognise these experiences (Dall'Alba, 2004; Dall'Alba & Sandberg, 2006). Ideally these external experiences are provided to the student as part of their professional formation, either through structured work experience or co-op programs, or through professional placement semesters (Radcliffe, 2002a; 2002b).

**Examples of the New Approach**

An example of designing a learning experience to develop students' ways of experiencing both the practice of engineering and sustainable design is the first year engineering orientation day at The University of Queensland (Crosthwaite et al., 2003). The day was created to develop a positive understanding of engineering practice within first year students, as it was found that "many students arrive at University with the expectation of just doing 'figures and calculations, ie Solve for X', and are dismayed, bewildered or indifferent when more is required" (Crosthwaite et al., 2003, p104).

The core of the orientation day is a group activity based around an engineering problem with sustainability aspects. The student groups identify the requirements of their designs and categorise them into technical, environmental, social and economic requirements. The groups use these to design and construct their solution to the problem, which is then assessed by facilitators to find a winner. Student evaluations showed that ninety-three percent of those who responded thought that they had a better understanding of what engineers do in practice than before the activity.

Another example of developing practitioners' ways of experiencing engineering practice is the Master of Sustainable Practice at RMIT (Hadgraft, 2006). This program aims to develop a 'community of practice' of practitioners, focusing on developing their professional practice of sustainability. The program embeds an action learning model to explore specific projects the students are working on in their professional lives regarding sustainability. In this way, students are encouraged to develop their way of experiencing sustainability as well as engineering skill development.

The development of ways of experiencing professional practice could also begin before students formally start their engineering undergraduate degree. For example, The Engineering Link Group (2005) run two camps for high school students interested in studying engineering. Both the Engineering Link Project (Millican et al., 2005) and the Enterprise Management Project (formally the Future Engineers Australia Management Project) (Richards et al., 2005) develop students' experiences of engineering practice by the students acting as engineers and engineering entrepreneurs. Each camp is based around day-long activities where groups of students are posed real world engineering problems by practicing engineers, and must create innovative solutions. Focus is maintained on identifying and solving problems as a professional would. In this way, future engineering students can enter engineering programs with more comprehensive ways of experiencing engineering practice.

Sustainability and sustainable design will not be truly embraced in engineering curricula until the academics designing and teaching the curricula embrace the concepts themselves (Harding, 1999). A vital part of this is the recognition that while sustainable design is informed by science, it is a value-laden concept and thus has to be handled differently than more technical elements of the curriculum. Academics need to be encouraged to learn about sustainability and sustainable design themselves to become better role models for their students (Crofton & Mitchell, 1998). Academics need to not only have an up-to-date understanding of sustainable design in practice as well as being attentive to students' learning requirements, but "be able to teach in a way that takes account of all these [aspects]" (Dall'Alba & Sandberg, 2006, p402).

## 6.4 Wider Use of Phenomenography in Engineering Research

This thesis makes a methodological contribution to research in both aspects of engineering practice and engineering education. In practice, it offers a way of identifying the different ways that the same aspects of practice are experienced by different practitioners. In education, it proposes a means of assessing the impact of engineering education programs by examining the changes to students' ways of experiencing practice, rather than assessing the accumulation of content. This echoes the findings of Dall'Alba's study of medical students (Dall'Alba, 2004).

On a wider level, this thesis demonstrates that phenomenography is useful for investigating aspects of professional practice. Specifically in engineering research, phenomenography is good for exploring ill-defined topics in professional practice and professional development. Phenomenography provides rich data, and helps to make explicit what is hidden. It not only offers a way of exploring these topics, as in this thesis, but also tracking changes in existing areas.

This thesis also has implications for the field of phenomenography. It demonstrates that this mode of enquiry provides a valuable insight into aspects of professional engineering practice. It also adds to the growing number of studies that have examined experiences of aspects of the world (see Table 3), rather than aspects within a specific teaching or learning context.

## 6.5 Future Investigations

As this thesis presents an exploratory investigation of practitioners' ways of experiencing sustainable design, many avenues exist for further research. Specifically from this study, two immediate investigations would be to test the pragmatic validity of the results in improving both practice and education, as discussed in Section 4.7.1. Changes in practice that could be used to test the pragmatic validity include adopting the changes suggested in Section 6.2 within engineering projects, such as a greater focus on solving a problem, and looking at the larger societal and environmental context of problems.

Changes in education that could be used to test the pragmatic validity include evaluating changes to the engineering curriculum in focusing on developing students' experiences of sustainable design as an aspect of practice. Also, changes could be made to the learning environment to actively engage students in learning processes, encourage students to support and challenge each other's development, and require students to be reflective about what they are doing. The success or otherwise of these initiatives could be evaluated in a future phenomenographic study.

More generally, a future study could explore both how, at the extent to which, the practice of sustainable design is enhanced by critically reflecting on the way we understand and engage in it. This sort of study should be longitudinal in nature, examining ways of experiencing sustainable design before and after any intervention. This also follows calls by Dall'Alba & Sandberg (2006) for aspects of practice to be investigated in this way. Another approach could be to investigate practitioners within a specific company involved with sustainable design using a case study method (Yin, 1994). This could create a clearer picture of how sustainable design is carried out within an engineering company. It could also look to implement changes to current practices, including critical reflection on practice, using participant-observation (Yin, 1994).

Because of the exploratory nature of this thesis, other studies flowing from this thesis could include a further investigation of the ways of experiencing sustainable design within a similar group of practitioners in Australia. This may capture more variation in experiences, and help to form a clearer picture of how sustainable design has been experienced in practice. This could also be expanded to increase the possible variation in ways of experiencing using a wider participant diversity. For example, this could involve the inclusion of university students or members of the public. Further, the study could be expanded to include overseas participants, as cultural background would be a good source of variation. On the other hand, the focus could also be on the ways of experiencing in specific disciplines or on specific types of projects.

As some of the categories of description of sustainable design seem to be closely related to traditional design, a future investigation could examine practitioners' experiences of traditional design. This variation could be compared to that found for sustainable design to see what similarities and differences exist to better inform practice. Also, a phenomenographic study of experiences of sustainable design could be conducted in a 'typical' engineering company to increase the range of categories, and create a clearer picture of organisational change (as discussed in Section 6.2.3).

In Section 6.2.3 I argued that an organisation as a whole develops, in effect, its own 'way of experiencing' sustainable design when compared to other organisations. I argued that this occurs through the internal practices it uses, the culture and values it instils in its staff, the experiences of the staff that work for it, and the projects it chooses to work on. Future investigations should explore this idea more fully, developing both an approach for identifying the different ways organisations experience aspects of practice such as sustainable design, and subsequently using the approach developed.

Future work could also include investigating current practices of sustainable design education in Australia and around the world. While it is essential for engineering programs in Australia to include sustainable design, as discussed in Chapter 1, little is known about how this is being accomplished currently. This study could bring together best practice and offer insights to the challenges faced by educators trying to incorporate sustainable design into curricula.

Finally, future studies could use phenomenography to investigate the ways of experiencing other graduate attributes and more generally the process of developing as an engineer.

# 7 CONCLUSION

> *We can climb the mountain of sustainability, but not by pulling back. We must charge forward, and reach up, with all the strength, intelligence, wisdom, compassion, and determination of which our species is capable. And when we attain the summit, we will see the world from an entirely different perspective.*
>
> *(AtKisson, 2001, p15)*

This thesis has provided a substantial contribution to knowledge by identifying how a group of leading practitioners have experienced an aspect of engineering practice, namely sustainable design. All engineering students and increasingly practicing engineers are expected to have an understanding of sustainable design and be able to apply it in practice. This thesis argues that a professional's way-of-being, incorporating the way they understand aspects of their practice, forms the basis of how they act in practice. Identifying the ways practitioners have experienced sustainable design in the past is a vital step in its widespread education and adoption throughout engineering.

In Chapter 1, three research questions were posed for this thesis:

1. What are the variations in ways of experiencing 'sustainable design' among sustainable design practitioners?
2. What are the implications of this variation for the practice of sustainable design?
3. What are the implications of this variation for the education of future professional engineers about sustainable design?

(1) This thesis used a research approach known as phenomenography to identify five qualitatively different ways of experiencing sustainable design: Solution Finding; Reductionist Problem Solving; Holistic Problem Solving; Social Network Problem Solving; and A Way of Life. These can be seen in Table 6 and Figure 13. The descriptions of each of these ways of experiencing sustainable design together with the relationships between them combine to answer the first research question.

(2) Many implications of this variation for the practice of sustainable design were identified and discussed. In particular was the need for practitioners to move to more comprehensive ways of experiencing sustainable design to meet the challenges faced in the future. Some of these changes include the need to look holistically at a problem, and understand the wider societal and environmental context surrounding the problem. There is also the need for practitioners to switch from finding a solution to the client's stated requirements, to identifying and solving the client's problem collaboratively. The question of the personal nature that sustainable design has for some practitioners, who see it as a way of life, and what this implies for the future of engineering practice if we are to effectively move toward a sustainable future should be considered.

(3) The implications of the variation in ways of experiencing sustainable design for the education of engineers are described. The key implication of this variation is the need for a new model of professional development in engineering. This model incorporates the traditional notion of engineering skills, as well as the different ways of understanding practice. Taking both of these into account, engineers will be more able to effectively develop as competent practitioners and effectively practice in the future. In particular, a focus on moving to more comprehensive ways of experiencing sustainable design will enable engineers to meet the challenges of sustainability and sustainable design head on.

This thesis also calls into question the traditional practices of engineering education, including the decontextualisation of content from practice. This thesis shows that this process, apart from anything else, overlooks the development of students' ways of understanding practice. This is identified to be vital for students to become competent practitioners. Engineering education requires a paradigm shift to incorporate the knowledge, skills, values and attitudes traditionally at the centre of engineering programs within the development of students' professional ways-of-being.

This thesis began with a quote from Donald Schön, who stated that as practitioners we face a choice. To stay with what we know on the high, hard ground, or to descend into the swamp to face problems of greatest human concern. I chose to descend into the swamp, and help to confront what I believe to be the greatest problem we have ever, or will ever, face. This thesis is but one step in a long journey, but it is a start. Even the longest journey begins with a single step.

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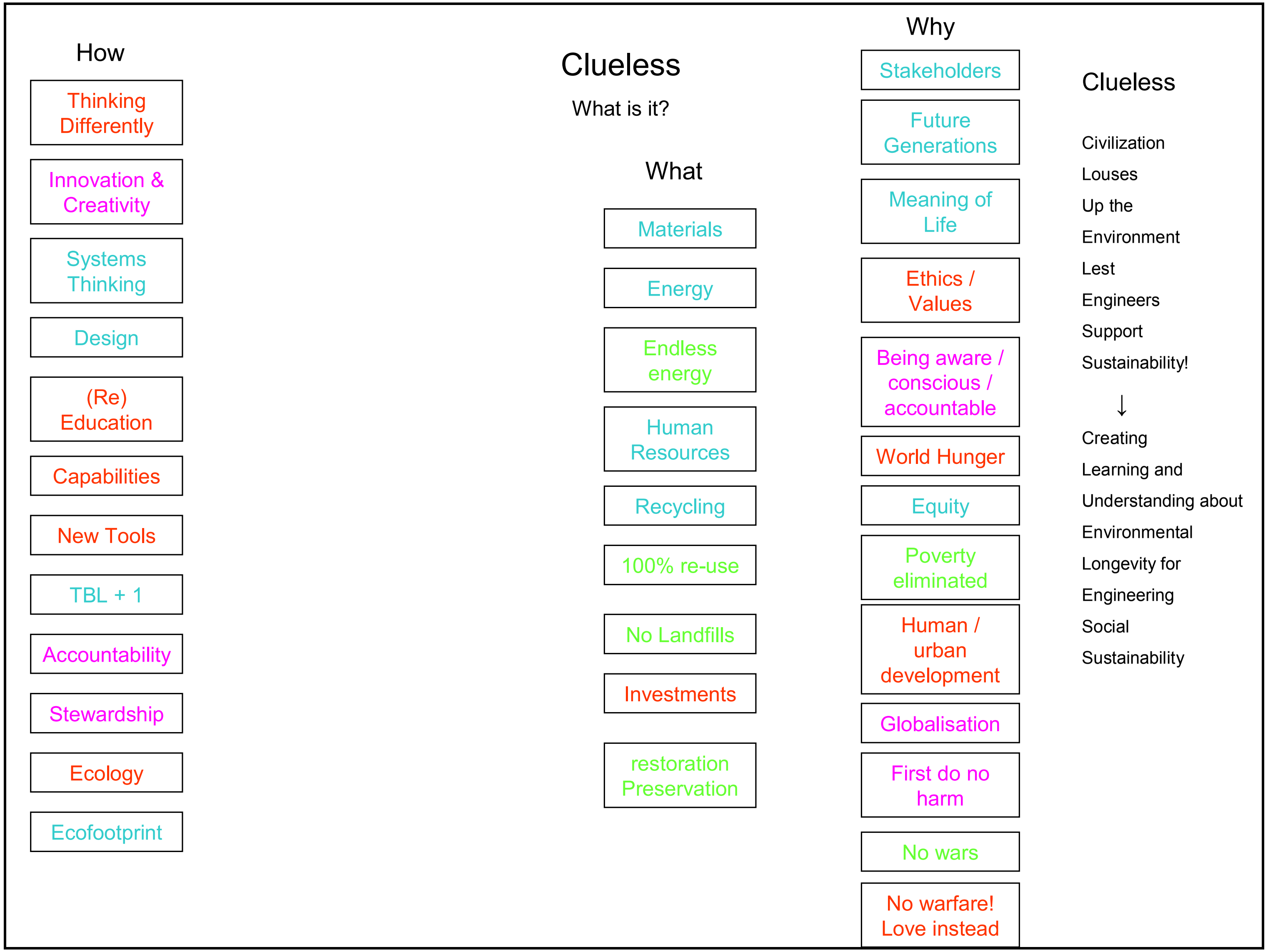
# Appendix A: Pilot Study Conception Maps

The order for the concept maps are as follows:

1. What is it?
    a. Clueless
    b. Future Facilitators
    c. Parhelion
    d. Phoenix
2. Who cares?
    a. Clueless
    b. Future Facilitators
    c. Parhelion
    d. Phoenix
3. What do students need to know?
    a. Clueless
    b. Future Facilitators
    c. Parhelion
    d. Phoenix


How
Thinking Differently
Innovation & Creativity
Systems Thinking
Design
(Re) Education
Capabilities
New Tools
TBL + 1
Accountability
Stewardship
Ecology
Ecofootprint
Clueless
What is it?
What
Materials
Energy
Endless energy
Human Resources
Recycling
100% re-use
No Landfills
Investments
restoration Preservation
Why
Stakeholders
Future Generations
Meaning of Life
Ethics / Values
Being aware / conscious / accountable
World Hunger
Equity
Poverty eliminated
Human / urban development
Globalisation
First do no harm
No wars
No warfare! Love instead
Clueless
Civilization
Louses
Up the
Environment
Lest
Engineers
Support
Sustainability!
↓
Creating
Learning and
Understanding about
Environmental
Longevity for
Engineering
Social
Sustainability

# Future Facilitators

→→→ Ideological ... Practical →→→

What is it?

- For everybody ie not just government / business
- Needs a long term view
- Equitable Living Standards
- A change of ideology
- Developing a world community perspective
- Viable Future
- Valuing Diversity
- Requires a holistic approach
- Lessening of third world/ first world division

- Begins with personal choices
- Ethical responsibilities
- Encourage self sustainability → personal choice

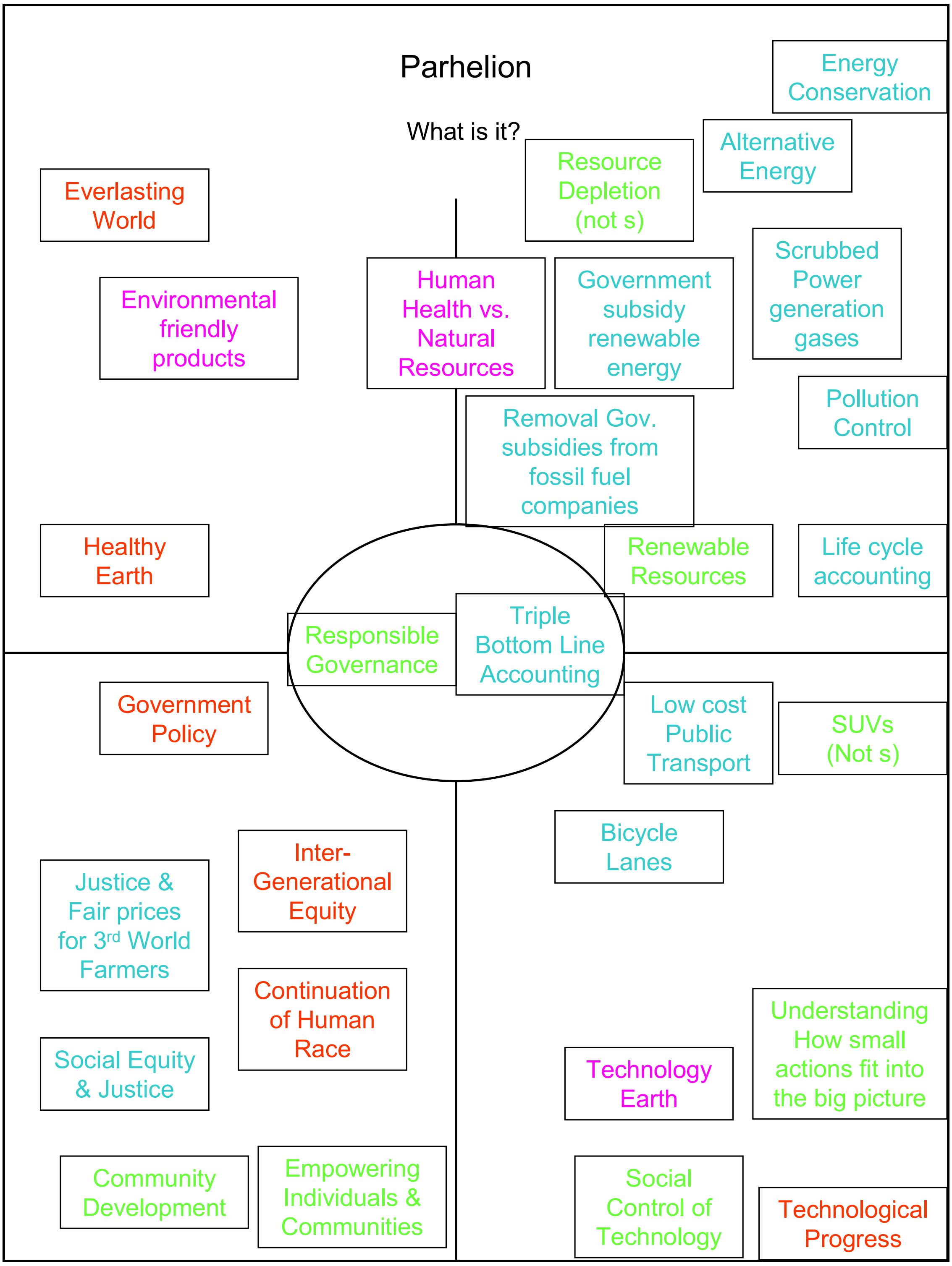
- Continuous economic growth
- Economic competitiveness with trading partners
- Being able to keep going
- Leaving environment in the same order in which it was found

- Designing systems using inputs and outputs which will always be ok
- Raising standards of education to include global society view
- Making decisions based on best knowledge of resource availability etc
- Considering all stakeholders in decisions
- Each human being taking a plan flight less than once in a lifetime

- NOT John Howard Policies
- Is more than just environmental compliance
- Difficult to implement / interpret locally
- A big word for some people
- Sometimes seen as a trendyism
- A difficult word to get across to young children who are the focus of the aim

- Efficient land use
- Biodiversity
- Smallest footprint possible
- Enough food for population

- Waste reduction
- Cleaner production
- Reduce / eliminate? waste
- Greenhouse gas reduction
- Reusability
- Minimizing Environmental Impact on Earth


Parhelion
What is it?
Energy Conservation
Alternative Energy
Resource Depletion (not s)
Everlasting World
Scrubbed Power generation gases
Environmental friendly products
Human Health vs. Natural Resources
Government subsidy renewable energy
Pollution Control
Removal Gov. subsidies from fossil fuel companies
Healthy Earth
Renewable Resources
Life cycle accounting
Responsible Governance
Triple Bottom Line Accounting
Government Policy
Low cost Public Transport
SUVs (Not s)
Bicycle Lanes
Inter-Generational Equity
Justice & Fair prices for 3rd World Farmers
Continuation of Human Race
Understanding How small actions fit into the big picture
Social Equity & Justice
Technology Earth
Community Development
Empowering Individuals & Communities
Social Control of Technology
Technological Progress

# Phoenix

## What is it?

- Natural Capitalism
- Learning from Nature
- Nature – Natural Resources
- Considerations for Future Generations
- <u>Equity</u> – Countries, business, people etc.
- Quality of Lives
- Social Justice

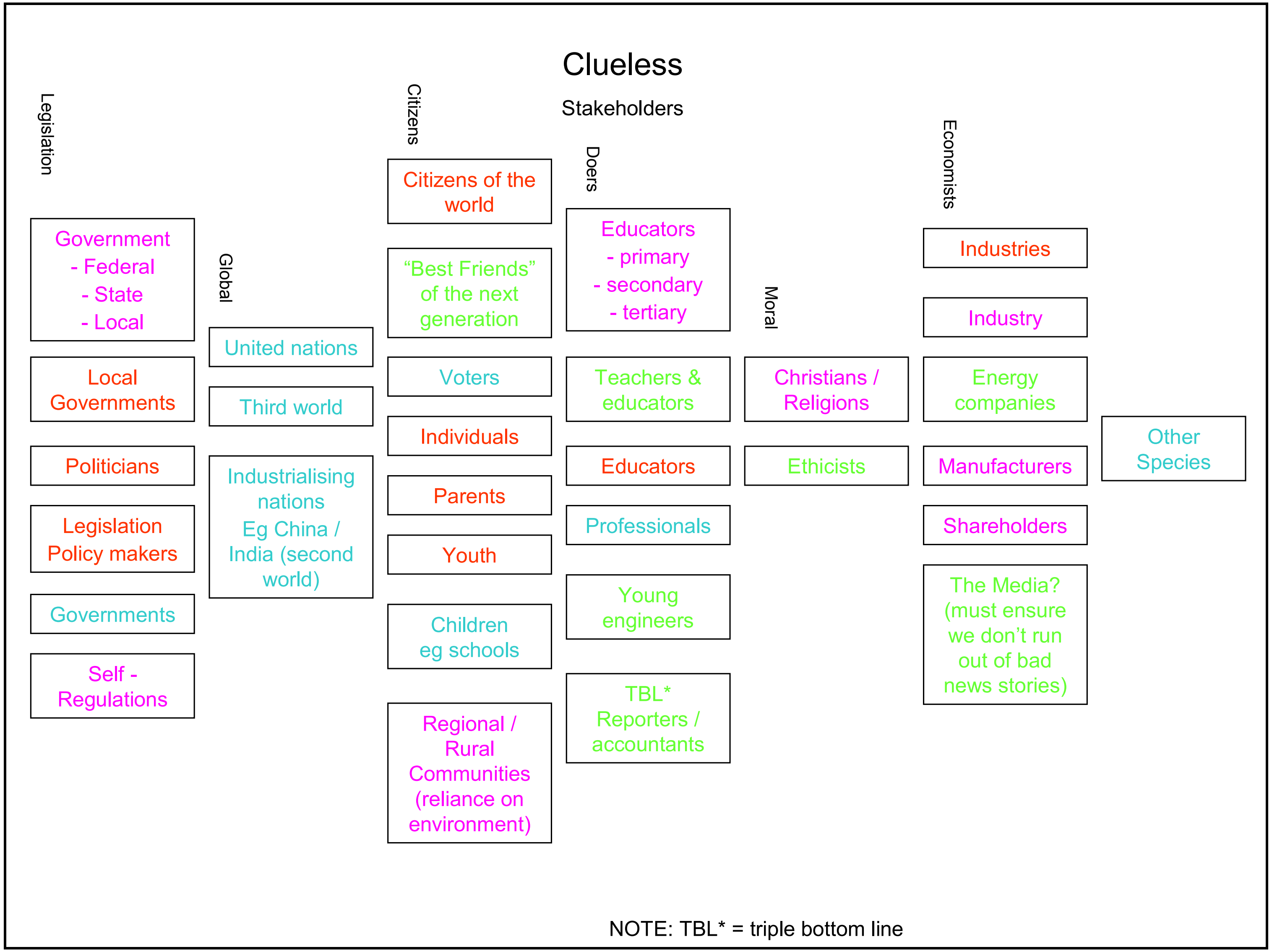
- Lifestyle Standards i.e. pollution Levels etc
- Being accountable & Responsible
- A set of values – something personal
- Future options
- People Planet Profit
- Putting back as well as taking out
- A new way of looking at things and of acting

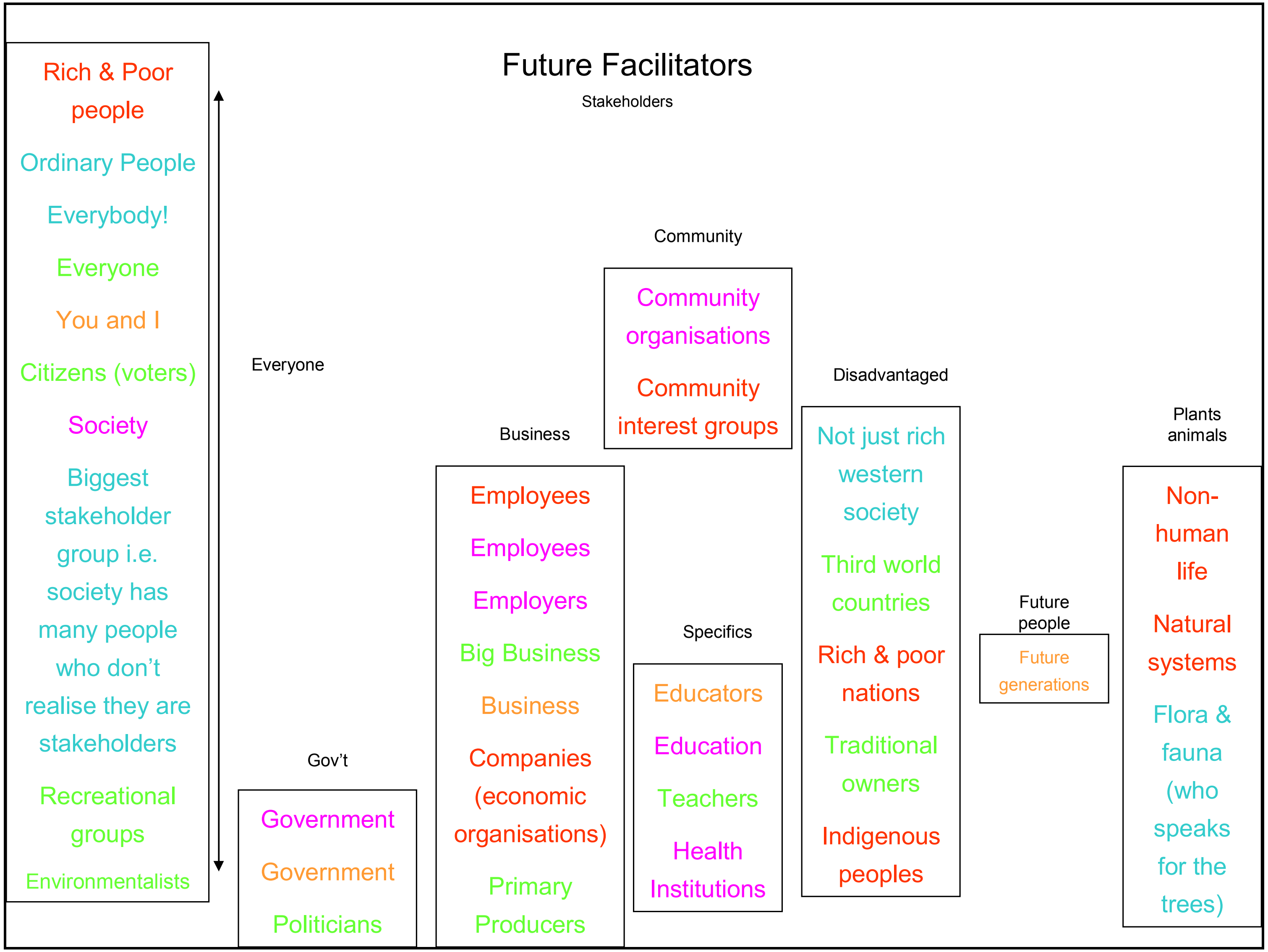
- Waste Resources
- Air Quality
- Water Resources
- Enhanced Transport Systems
- Energy Resources
- Innovative Energy Source
- Smart Development
- Management of and efficient utilisation of Natural Resources

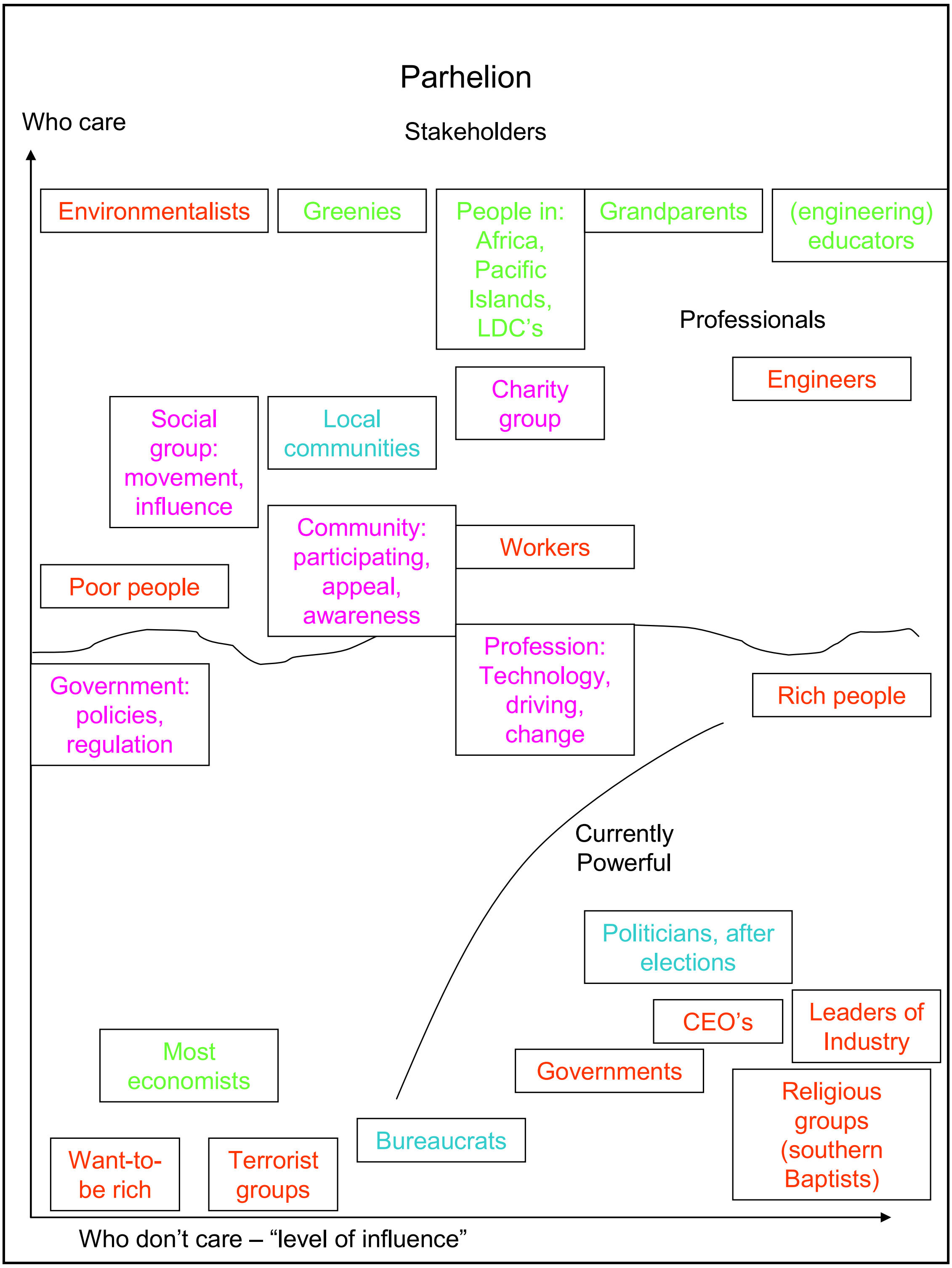
- Staying in Business
- Employment
- Waste Resources
- Contemporary
- Comprehensive
- Justified
- Well Defined

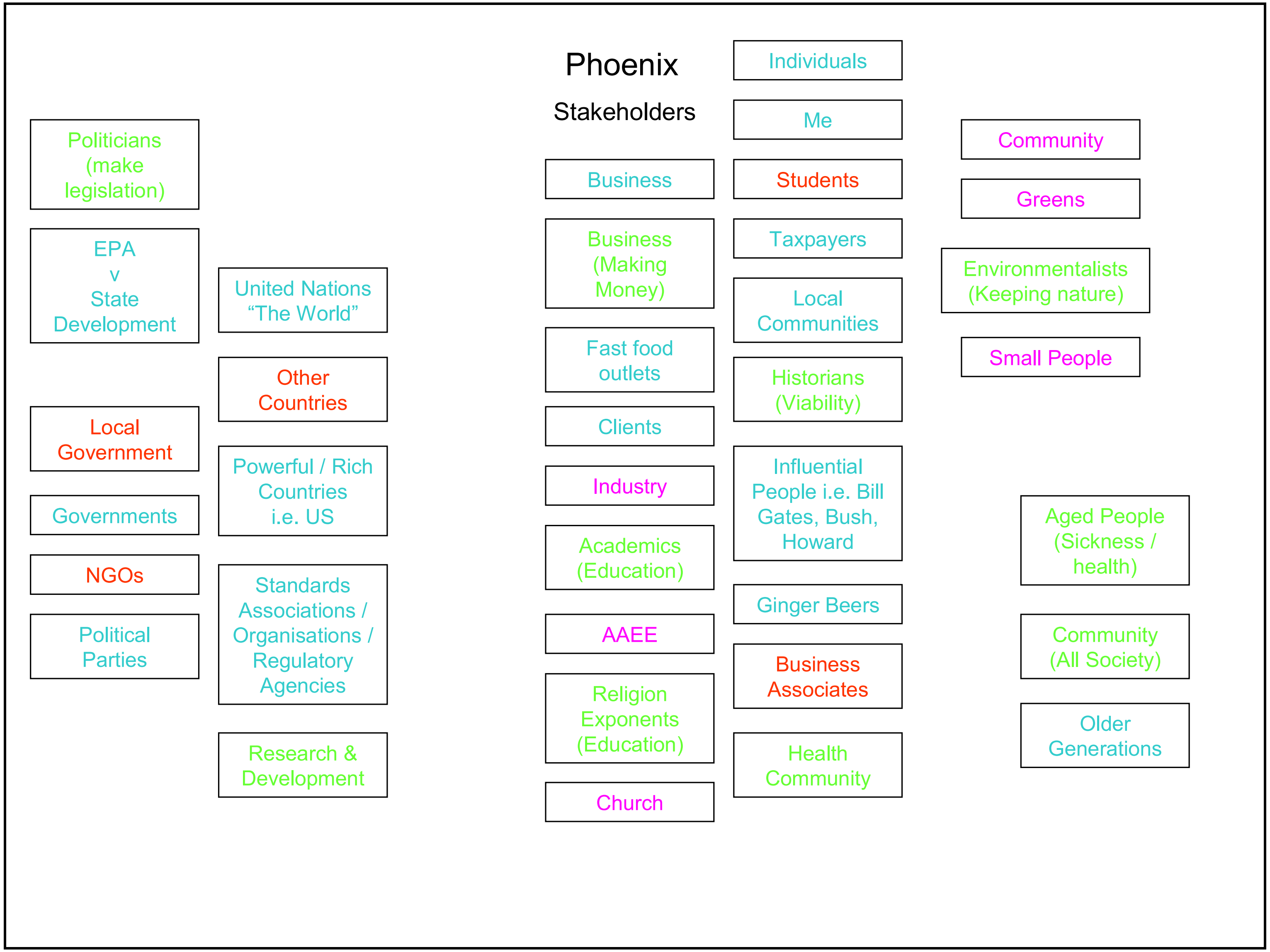
<u>Q</u>

- Sustainability
- Sustainable Development
- Sustainable Design


Clueless
Stakeholders
Legislation
Government - Federal - State - Local
Local Governments
Politicians
Legislation Policy makers
Governments
Self - Regulations
Global
United nations
Third world
Industrialising nations Eg China / India (second world)
Citizens
Citizens of the world
“Best Friends” of the next generation
Voters
Individuals
Parents
Youth
Children eg schools
Regional / Rural Communities (reliance on environment)
Doers
Educators - primary - secondary - tertiary
Teachers & educators
Educators
Professionals
Young engineers
TBL* Reporters / accountants
Moral
Christians / Religions
Ethicists
Economists
Industries
Industry
Energy companies
Manufacturers
Shareholders
The Media? (must ensure we don’t run out of bad news stories)
Other Species
NOTE: TBL* = triple bottom line


Future Facilitators
Stakeholders
Rich & Poor people
Ordinary People
Everybody!
Everyone
You and I
Citizens (voters)
Society
Biggest stakeholder group i.e. society has many people who don't realise they are stakeholders
Recreational groups
Environmentalists
Everyone
Gov't
Government
Government
Politicians
Business
Employees
Employees
Employers
Big Business
Business
Companies (economic organisations)
Primary Producers
Community
Community organisations
Community interest groups
Specifics
Educators
Education
Teachers
Health
Institutions
Disadvantaged
Not just rich western society
Third world countries
Rich & poor nations
Traditional owners
Indigenous peoples
Future people
Future generations
Plants animals
Non-human life
Natural systems
Flora & fauna (who speaks for the trees)


Parhelion
Who care
Stakeholders
Environmentalists
Greenies
People in: Africa, Pacific Islands, LDC's
Grandparents
(engineering) educators
Professionals
Engineers
Social group: movement, influence
Local communities
Charity group
Community: participating, appeal, awareness
Workers
Poor people
Profession: Technology, driving, change
Government: policies, regulation
Rich people
Currently Powerful
Politicians, after elections
CEO's
Leaders of Industry
Most economists
Governments
Religious groups (southern Baptists)
Bureaucrats
Want-to-be rich
Terrorist groups
Who don't care – "level of influence"


Phoenix
Stakeholders
Politicians (make legislation)
EPA v State Development
Local Government
Governments
NGOs
Political Parties
United Nations "The World"
Other Countries
Powerful / Rich Countries i.e. US
Standards Associations / Organisations / Regulatory Agencies
Research & Development
Business
Business (Making Money)
Fast food outlets
Clients
Industry
Academics (Education)
AAEE
Religion Exponents (Education)
Church
Individuals
Me
Students
Taxpayers
Local Communities
Historians (Viability)
Influential People i.e. Bill Gates, Bush, Howard
Ginger Beers
Business Associates
Health Community
Community
Greens
Environmentalists (Keeping nature)
Small People
Aged People (Sickness / health)
Community (All Society)
Older Generations

## Clueless

What do students need to know?

After fully explaining technical issues, students arrived at a social solution. I was delighted

Poor attitudes: it doesn't affect software engineers"

Sustainability needs to be integrated in our curriculum. It is not a separate add-on

We need to promote the sustainability angle when promoting / describing engineers to primary and high school students

Team projects for first year students – multidisciplinary teams and projects

Ecofootprint

Project – based learning

Natural edge project

Member of a sustainable department forum at university

Resource development manager (web based)

Recycling eg mobile phones, computers

GU – environmental engineering

Engineers Australia & united nations

"natural edge project"

Should we dredge the shipping channel in Port Philip Bay?

Teaching and research involvement at university

Life cycle assessment

Political Activism

## Future Facilitators

What do students need to know?

Introduce students to life cycle assessment techniques and software – small case study

Need for political awareness

Material selection

Chemical technology as vehicle for greenhouse effect

Practice: projects

Change in ideology / culture

Embedded somewhat in our environmental engineering programme

Sustainability becomes an actual theme in all my teaching

Practice: case studies

Getting an expert from natural edge project to teach sustainability modules

Must do more than just tell students – need to actively teach skills and techniques

Ask students to assess sustainability of electronic products – using Rio 92 ideas (10 categories)

Students need more tools to assess sustainability

## Parhelion

What do students need to know?

Project on recycling grey water

Awareness of engineering as a social activity

Solar car project 1st year management

Appropriate Technology

Debate on wind farm locations

Technology management

Hypothetical on production – pollution labour issues

Debate on future Australian manufacture

Refuse

Reuse

Reduce

Recycle

Recycle materials

Best beginning practice

Student project on world bank / IMF

Using renewable resources

Optimum performance

Social awareness

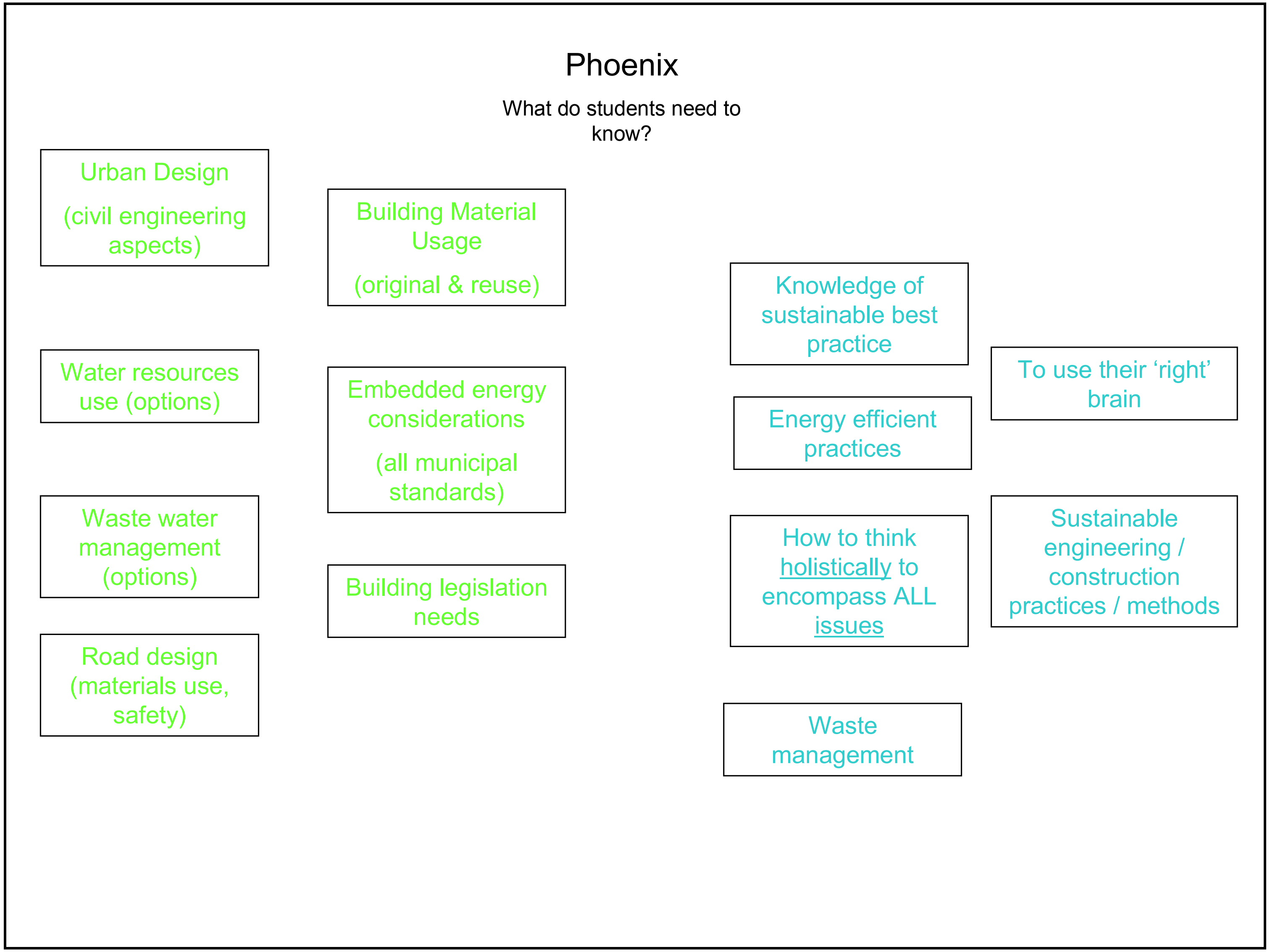
Professional ethics

Social awareness

Quality of life vs standard of living

Life cycle analysis

Life experiences


Phoenix
What do students need to know?
Urban Design
(civil engineering aspects)
Water resources use (options)
Waste water management (options)
Road design (materials use, safety)
Building Material Usage
(original & reuse)
Embedded energy considerations
(all municipal standards)
Building legislation needs
Knowledge of sustainable best practice
Energy efficient practices
How to think holistically to encompass ALL issues
Waste management
To use their 'right' brain
Sustainable engineering / construction practices / methods

# Appendix B: Revised Stakeholder Groups

- Australian Industry, including
  - Private companies
  - Peak industry bodies, both national and international
  - Unions
  - Shareholders
- Government
  - Local, state, federal
  - Political parties
  - Regulators
- The Engineering Profession
  - Chapters
  - Societies
  - Accreditation Board
  - Young Engineers
  - Other Professional Institutions
  - Other Professions
- Education
  - Schools (High, Primary)
  - Universities

    - TAFE
    - Training
    - Students
- The Community
    - Local groups impacted by engineering operations
    - National Non-Government Organisations (NGO's)
    - Charity Groups
    - Lobby Groups
    - Consumers
    - Families
    - Religious Groups
- Research and Development Groups
- The Media
- Standards Associations
- Champions of Sustainability

- International NGO's
- Future Generations
- First World Nations
- Industrialising Nations
- Third World Nations
- Other Species

# APPENDIX C: CONTACT LETTER TO PARTICIPANTS

Their Address

# RE: Involvement in Study on Ways of Experiencing Sustainable Design

Dear Mr Bloggs,

My name is Llewellyn Mann and I am a PhD student at the University of Queensland. I am currently conducting a study into ways of experiencing 'sustainable design' within an engineering context. Jane Doe suggested that you would be a good person to talk to about your experiences with sustainable design.

I am contacting you regarding your possible involvement in this study. The expected duration of your participation in the study would be one interview of approximately one hour duration. The involvement would take the form of a one-on-one interview relating to your experiences with sustainable design in projects. The interviews will be audio recorded then transcribed in a de-identified format. No individuals will be identified in any reports of this study. The results of the study will be used in the future education of student engineers, as well as to further the discussions within the engineering profession and the wider community about these issues. The personal benefits of you being involved in the study include a greater awareness of what these concepts mean to you, as well as access to the final results of the study.

The interviews will be conducted in private at a location that is easiest and most convenient to you. If you agree to participate and at a later stage wish to withdraw your interview, no judgement or prejudice would be made and the interview data would be destroyed and a letter sent to you informing you that this has been done.

This study has been cleared by one of the human ethics committees of the University of Queensland in accordance with the National Health and Medical Research Council's guidelines. You are of course, free to discuss your participation in this study with project staff (contactable on 33469913). If you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Officer on 3365 3924.

If you are interested in being part of this study, or would like more information, please feel free to contact me on (07) 3346 9913 or at l.mann@uq.edu.au. I will ring you to follow up this letter and talk about your possible involvement.

Regards,

Mr Llewellyn Mann
PhD Candidate
The Catalyst Centre for Society and Technology
School of Engineering
The University of Queensland
Ph: (07) 3346 9913
Email: l.mann@uq.edu.au

Professor David Radcliffe
Thiess Professor of Engineering Education and Professional Development
School of Engineering
The University of Queensland
Ph: (07) 3365 3579
Email: d.radcliffe@uq.edu.au

Dr Gloria Dall'Alba
Senior lecturer
School of Education
The University of Queensland
Ph: (07) 3365 6658
Email: g.dallalba@uq.edu.au

# APPENDIX D: INTERVIEW PROTOCOL

# Interview Protocol

Remember
Don't talk too much
Use "that's interesting" rather than "that's good"
Use "tell me more about that", "What do you mean by X", "could you give me an example"
Guard against assuming any terms they say

Thank you for agreeing to participate in this study.

1. Explain what the study is about:
    a. Purpose: researching experience of SD among SD practitioners situated within engineering projects
    b. Results to be used to help the future education of engineers, as well as to further discussions generally about SD
    c. One interview of approximately one hour. Free to withdraw at any stage.
    d. Audio recording – so I don't have to frantically write notes and can transcribe accurately later
    e. Confidentiality – the interview will be de-identified using pseudonyms for any reports from the study, only myself and my PhD advisors will have access to the recordings
    f. Welcome to look at the products of my research
    g. No 'correct answers', I am only interested in your experiences
    h. How long have you been involved with design activities?
    i. Have you had any formal training involving sustainable design? If so, what?
    j. Any questions?

2. Can you describe a practical experience you have had that involved sustainable design?
    a. What did that experience involve?
        i. Scale?
        ii. Location?
        iii. Client?
        iv. Type of delivery?
        v. Groups involved?
    b. <u>What did you do in this project (concrete)?</u>
    c. <u>In what way did it involve sustainable design?</u>
    d. <u>Why was that so important?</u>
    e. <u>What did a typical day involve?</u>

3. Can you describe another practical experience you have had that has involved sustainable design?
    a. How do you think this is different from the experience we talked about earlier?

4. What would you say sustainable design is, for you?

5. Do you think that your views on sustainable design have changed over time?
    a. If so, in what way?
    b. If not, why do you think this is?

6. Can you think of a specific time or issue that challenged your view of what sustainable design meant for you?

7. Do you have anything else you want to add about Sustainable Design?

8. Do you have any questions of me?

Thank you for your time.

# APPENDIX E: INFORMED CONSENT FORM

# Informed Consent for Involvement in Study

**Interviewer**
Mr Llewellyn Mann
PhD Candidate
The Catalyst Centre for Society and Technology
School of Engineering
The University of Queensland
Ph: 33469913
Email: l.mann@uq.edu.au

**Title**
Ways of Experiencing Sustainable Design in Engineering Operations: A Phenomenographic Investigation

**Purpose**
The purpose of this study is to investigate the variation of ways of experiencing 'sustainable design' within an engineering context. The results of the study will be used in the future education of student engineers, as well as to further the discussions in the professional engineering community about these issues.

This study is being conducted as part of a PhD and consequently the data will be owned by the University of Queensland.

The results of the study will be published in the PhD thesis, as well as journal articles and conference papers.

**Procedures for Involvement**
The involvement will be in the form of a one on one interview of approximately one hour in which the participant will be asked a set of open ended, semi-structured questions relating to sustainable design. The interviews will be audio recorded then transcribed. The data will be kept for a period of five years, with no one else able to use the data obtained.

**Benefits of Involvement**
The personal benefits of being involved in the study are a greater awareness of what these concepts mean to the individual participants as they reflect on their own conceptual understandings.

The participants will also be given feedback in terms of the results of the analysis to help further their understandings of sustainable design and development.

**Confidentiality, Privacy and Security**
The interviews are voluntary and will be conducted in private, with only the participant and the interviewer present. The interview will be audio recorded, transcribed and stored in a locked filing cabinet in de-identified form. Only the interviewer and his PhD advisory group (Prof David Radcliffe and Dr Gloria Dall'Alba) will have access to the recordings.

The interviews are confidential and individuals won't be identified in any reports of the study. If the interviewee at any time wishes to withdraw his or her interview, no judgement or prejudice would be made of them by the interviewer. The interview data would be destroyed and a letter sent to the interviewee informing them that this has been done.

**The University of Queensland's Ethical Paragraph**
This study has been cleared by one of the human ethics committees of the University of Queensland in accordance with the National Health and Medical Research Council's guidelines. You are of course, free to discuss your participation in this study with project staff (contactable on 33469913). If you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Officer on 3365 3924.

........................................................................................................................................

I, ______________________________________ give my informed consent to being part of this study. I have read the above information and I agree with the terms of the study.

__________________________________________ _____ / _____ / _____

Signature

# APPENDIX F: SAMPLE INTERVIEW TRANSCRIPT

**Page 1**

**Llew:** Ok well can you tell me about an experience that you've had with sustainable design or, or whatever you want to call it?

**Brett:** The [project] and that was probably the one as a sign project, as a signature project I'm involved with and I can talk from experience in that respect. That project has since won, last count it was about twelve or fifteen, I can't remember, awards for sustainability. It went through a number of different processes in that respect. As principal consultant for delivering the project I had to, one delivered what they call a local plan integrating that with the […] City Council Town Plan, developing up all guidelines for future developments and addressing sustainability at the same time; doing the design documentation and then construction implementation for effectively the sub division um, and again, addressing sustainability issues but primarily focusing on civil engineering rather than building engineering and it's a fairly rudimentary civil engineering. A lot of the outcomes that were or have been developed into sustainability are incredibly basic, very, very simple common sense approach outcomes. To some degree I believe we have… sustainability is looking back to the past and realising my god, they had it right back in 1930 and why didn't we learn from the past.

A classic one in Queensland is the Queensland, Queenslander style house, tin and timber sitting on stumps; ventilation's fantastic; um it's got, it's off the ground for moisture issues; you looked at the environment, the natural environment that it was in and it blended in with that environment, there's a whole host of different elements that were in there. We are entering a phase where um, our populations are densifying and consequently we can't sustain the tim timber type avenue. However, the the principles are exactly the same. One one of the things we er, we did in 1970 I think it was, if you look at residential developments, AV Jennings introduced the slab on ground house to Queensland that was the demise of um, a lot of natural environment. It gave a um, product to the community, the community accepted that product as being modern, acceptable and therefore embraced it and now is complaining about the fact that we've or, we've denuded the landscape of trees; we've created houses that are hot and claustrophobic and we're not being sustainable. Well, guys, that's what you asked for at the beginning of the day, sort of thing, so that's some of the things that [project] has brought out, is that it's not so much what we did; it's the fact that we put it together in one package, but it was just basic common sense approach to um, aspects that people have been trying to engineer um, or de-engineer out out of, out of buildings sort of thing and then making wrong turns all the way through.

**Page 2**

**Llew:** So what sorts of things did you try to incorporate within, within the plans for that?

**Brett:** Like in the, in the planning guidelines there was cross ventilations. We looked at the um, reuse of materials from the, or from the existing site, there were demolitions so we reused a lot of the timbers within the urban landscape, but in the new buildings we looked at cross ventilation. Orientation of buildings was key. The actually orientation of the buildings was actually dictated by the orientation of the roads, that there was some playing around with the actual sub division at the, at the beginning to make sure that all buildings in the future had good orientation. We looked at the typography of the lands to look at ventilation and how that would affect future developments. It also plays into, orientation also plays into where water is going to run off and collect and then view lines come into that aspect. In sustainability it not only looked at the environmental aspect, we looked at the the social aspect and what the mix in [project region] has got an eclectic mix ranging from an aged person's home which is immediately on one boundary, allowing that to integrate into the site which has got a university that um, encompasses from pre-school, there's a pre-school, a child care centre, a school, a university, residential, commercial um, and retail all blended within the [project]. That mix of the community is paramount to the whole sustainability issues.

The third thing was to make sure that it was functionally viable, you know that people were going to actually save money by being there, that people were going to make money by being there. The commercial aspect is going to make money by the community actually wanting to go there and being a thriving thriving little community. And I could never, when with the team we had architects and landscape architects, urban designers. When we were talking together the urban designers were always talking about having a busy street and they were using Park Rd, Milton as an example or Melbourne St, West End or James St, The Valley or the one down at Bulimba, Oxford St, Bulimba. All of those, if you have a look at them, have a, the street has a long street but the active area is only about two hundred metres long and if you try to understand why does it work, why does that active area work, I came to the conclusion it's more like a fight in a in a in a um, in a public area or something that's happening, seagulls flying to a chip, they don't know what's there at the beginning but the crowd creates interest. People go to the crowd to see what's there and while they're there they take part. So that sort of thing happens, if you slow the traffic down on a road it creates congestion, people then feel that there's crowd has been created and more people are actually drawn to that centre and magnifies to that centre.

Consequently, the area, the shops in the area actually thrive because that's that business and, humans are a type of an, are an animal that actually thrives on on ganging together, collecting together. So when we actually have those small dense packs, we actually feel comfortable and we spend money and, and the like, so that's another part of the sustainability, is to make sure that it creates that community and that's where the urban village actually came from and it took me probably six months into the project before I realised that the word village didn't mean thatched houses and low dwellings. Village means community and that definition of village is actually what [project] is all about, that you can have [project location] because of locality; urban because of the style and format of the buildings; and village because of the community. Blend those altogether and how we actually handled water, air and light through the whole site and then how people actually would live and work within that community was built into the whole um, project from the town planning right through to onto the ground and it's still being implemented at the moment through some of the buildings that are in progress.

**Page 3**

**Llew:** You mentioned a couple of things that I'd like to come back to. One was you said that the orientation of the buildings was was key and critical. You can elaborate on why you, why you think that is?

**Brett:** Solar er, temperatures are quite important, orientating the building so that they take advantage of having the the spatial areas to the north north-east; maximising the temperature range in the comfort zone for humans um, and we minimized, and we also put, the western sun or south-western areas are usually the detrimental areas or the the hottest areas, so those areas we tended to try and put the orientation such that you have your service areas or back of house sitting orientated in that direction. It's quite difficult because you know there's two sides there. If you have a look at the streets, they actually face in a um, I think it's a North-East, south-west direction and most of the buildings will have, their their views are actually back over to Victoria Park which is on the East, East to North-East aspects. There will be some lower areas to the west south-west, but you'll have overlooking buildings within that area.

That's another thing we're conscious of in the whole process is what they call CePTED, crime prevention through environmental design and that um, is an im, a significantly important aspect in today's community, to actually reduce the amount of policing that's required by survel, passive surveillance by the community itself and that gets back to this village aspect. If you think of a village, a small village that everyone knows everyone else, everyone looks after each other, the same thing happens in an urban village, although you don't necessarily know all the people but you do get to know faces and the like and you you tend to look after them. A bit of an example is that guy called Ziggy at Toowong. No-one really wants to know him but everyone knows that he's there and everyone looks after him by just driving past and the like, so it's it's that style of thing. You don't actually personally know the person but you know the character and you look after that character. The same thing happens in a community like an urban village where you might see people around, you might not know them personally but you still, as a community, look after them.

**Llew:** Um, one of the other things you did mention was the mix of community and you were mentioning the different types of people that were within and you said that that's paramount. Can you just, sort of, elaborate on why you think that's so important to get that mix?

**Brett:** Well, we… as engineers all we are doing is providing shelter and food or ability or services for life but we are human and humans require other humans to actually, we need that contact and we don't have contact, if we have contact with people of the same race, same age, we would find it very um, dull, boring. By having a a a mix of age and race and um, er, backgrounds we find that diversity. The diversity creates the interest and keeps us sane, keeps us interested and keeps us on, going to the next stage sort of thing.

**Llew:** I'm interested as well in this, in this crime prevention through environmental design. I've never heard about it before. How is that actually implemented? Can you explain a little bit about that?

**Brett:** With with the planning phase, all buildings on on corners have to have balconies or windows so that there was an aspect where they could overlook streets. There's no enclosed corners or or recessed areas where people can hide behind. We don't, tend to not like, or don't have tunnels um, the reason, or areas where people can actually hide behind a corner and jump out and grab someone or take someone to a to a hidden space or a recess or like a cave where they can actually hide within that cave and and um do unobserved sort of activities within the public realm. Obviously you've got you're you're your private entities. You can't help those. This is only in the public area. So the, for example, in a tunnel you might design it such that the approach to the tunnel is not immediately square to it, that there's a long line of sight right through so you can see from one end to the other and you can see that there's no-one actually hiding in the tunnel. Tunnel lengths become an important point. If they get too long there's not enough over viewing so they're kept to a minimum if you do have them, but you've got to be able to see straight through them.

**Page 4**

Within on the, as I said, on the intersections and the street there's overlooking and we get that from a number of different angles so that we don't have, or create returns around buildings that allow people to actually hide behind those areas and attack people or do, do things. That's really what crime prevention through environmental design is about is um, crime prevention, also providing adequate lighting so you don't have dark spots, so that there's, like all the pathways are well lit at night, that you're close to, there's not very long isolated areas or walkways um, so that people can walk with comfort at night time. Crime prevention, so we want to minimise the amount of crime, the types of crimes that occur in public, muggings, sexual assaults and the and the like, so we prevent those type of crimes through environmental, the environment that you're actually sitting in and the design of that environment, that's all it means.

# APPENDIX G: FIRST ITERATION OF CATEGORIES OF DESCRIPTION

### 1. Sustainable design is finding a solution, either technical or physical that minimises the associated environmental, social and economic impacts. (n=3)

The focus is on developing a solution to known parameters. This has an underlying premise that there can indeed be a solution and is this is thus a very deterministic stance, where technology offers the answer to sustainable design issues. These solutions are either physical or technical artefacts that will minimise the environmental, social and economic impacts. This is a focus on minimising harmful impacts through the better design of physical artefacts.

### 2. Sustainable design is finding a solution, either people or process that minimises the associated environmental, social and economic impacts. (n=4)

The focus here is again on developing a solution, but the solution involves changing either people or processes, rather than producing a physical, technical artefact. It is still a deterministic stance, but that takes into account that it is people and process that need to be changed rather than just the artefacts that the people or processes produce. It is still aimed at minimising the harmful effects these have on the environment, society and the economy.

### 3. Sustainable design is solving a problem, by balancing the individual decisions taken to minimise the associated environmental, social and economic impacts. (n=3)

The focus here is solving a problem, as opposed to finding a solution. This difference is significant because a focus on solving problems potentially allows underlying or larger problems to be uncovered and solved. The problem solving process involves balancing individual decisions, one by one, to minimise the negative impact to the environment, society and the economy. This problem solving process could still produce a solution that is either a physical artefact or a change in people or processes, but the focus is on the problem.

### 4. Sustainable design is solving a problem, by viewing the problem on a systems level with every part impacting other parts, to increase the associated environmental, social and economic value. (n=2)

The focus here is still on solving a problem, but it differs from the above category in that the approach is on a systems level. Rather than identifying and addressing each issue individually, a systems level approach is used, where each decision impacts other elements. The problem is solved thus by looking at the system holistically and all the possible impacts that come from solving the problem in a certain way. There is also a change from reducing environmental, social and economic impacts to increasing their associated value. This is also significant as sustainable design is seen as a ‘positive’ activity to make things better, rather than a ‘negative’ activity to make things ‘less worse’.

## 5. Sustainable design is solving a problem that is part of a network of problems on a professional level to increase the associated environmental, social and economic value. (n=5)

The focus here is still on solving a problem, but the realisation that the problem being solved is part of a larger network of problems, and that each problem cannot be solved in isolation. These problems though are solved on a professional level only as a designer, and again aim to increase the environmental, social and economic value. This includes looking at each problem on a systems level, but then also looking at how each system fits into a larger network of systems.

## 6. Sustainable design is solving a problem that is part of a network of problems on a personal level to increase the associated environmental, social and economic value. (n=5)

While the focus is still on solving a problem as part of a network of problems, the main difference from the previous category is the change from just looking at problems on a professional level to looking at them on a personal level. While this personal stance also includes professional aspects, the personal and professional aspects can not be separated or 'turned off'. The aim is still to increase the environmental, social and economic value.

# APPENDIX H: FOURTH ITERATION OF CATEGORIES OF DESCRIPTION

The term client used throughout is a general one, referring to the body that has engaged the designer to carry out design work.

### 1. Sustainable design is developing a solution to satisfy the client's stated needs for a final physical product while minimising its associated environmental, social and economic impacts. (n=3)

The focus is on developing a solution to the client's needs. The solution takes the form of final physical product that is designed to minimise harmful environmental, social and economic impacts. The notion that it is a physical product is core, and the design activities are centred on producing this product.

### 2. Sustainable design is developing a solution to satisfy the client's stated needs for a final physical product by changing the human aspects and or processes involved in producing the product, in order to minimise environmental, social and economic impacts of that product. (n=4)

The focus is on developing a solution to the client's needs, which involves focusing on changing the human aspects or the processes that produce the final physical product, rather than directly on the final product itself. It is the processes and the people behind the processes that are important to sustainable design. By changing these people and processes, the harmful impacts on the environment, society and the economy from producing the final physical product are minimised.

### 3. Sustainable design is the process of solving a client's problem by producing a product by making discrete decisions independently that each try to minimise the associated environmental, social and economic impact. (n=3)

The focus is on the process of solving a client's problem. A final product is produced, but it is in response to a problem rather than a statement of what the client needs. The process involves making decisions, but these decisions are made independently from each other. These decisions each try to help solve the problem while minimising the environmental, social and economic impacts from those decisions.

### 4. Sustainable design is the process of solving a client's problem, by making decisions holistically on a systems level, to increase the environmental, social and economic value of the solution. (n=2)

The focus is on the process of solving a client's problem holistically on a systems level. Taking this approach, each decision made impacts other elements of the system. A final solution is produced to address the client's problem. The process of designing this solution involves trying to increase the environmental, social and economic value of the solution considering all the decisions that are made.

5. Sustainable design is the process of solving a client's problem, with the understanding that it is part of a network of wider problems facing society, by making decisions holistically on a systems level that increase the environmental, social and economic value of the solution to both the client and society. (n=5)

The focus is on the process of solving a client's problem holistically on a systems level. There is a realisation thought that the client's problem is part of a larger network of problems. The solution that is produced in response to the problem tries to increase the environmental, social and economic value of the solution within both the smaller problem for the client and wider network of problems for society. This is done by considering how each decision impacts other parts of the system, and the wider network of problems.

6. Sustainable design is a way of life that embraces solving any problem, professional or personal, with the understanding that it is part of a network of wider problems facing society, by making decisions holistically on a systems level that increase the environmental, social and economic value of the solution to all. (n=5)

The focus is on sustainable design as a way of life that permeates all the decisions the designer makes. There is no separation between work done as a professional designer or as a person. The core process is that of solving problems to facilitate this way of life. The problems solved may be provided by a client, but they are solved to increase the environmental, social and economic value of the solution more for the wider society than for the client.

# APPENDIX I: SIXTH ITERATION OF CATEGORIES OF DESCRIPTION

The term client used throughout is a general one, referring to the body that has engaged the designer to carry out design work.

## 1. Physical Productors

### Sustainable design is developing a solution to satisfy the client's stated needs for a final physical product while minimising its associated environmental, social and economic impacts. (n=3)

The focus is on developing a solution to the client's needs as stated. The solution takes the form of final physical product that is designed as to minimise its harmful environmental, social and economic impacts. The notion that it is a physical product is core, and the design activities are centred on producing this product.

## 2. Processors

### Sustainable design is developing a solution to satisfy the client's stated needs for a final physical product by changing the human aspects and or processes involved in producing the product, in order to minimise environmental, social and economic impacts related to the product. (n=4)

The focus is on developing a solution to the client's needs as stated, which involves focusing on changing the human aspects or the processes that produce the final physical product, rather than the final product itself. It is the processes and the people behind the processes that are important to sustainable design. By changing these people and processes, the harmful impacts on the environment, society and the economy from producing the final physical product are minimised.

## 3. Problem Balancers

### Sustainable design is the process of solving a client's problem with a product developed by looking at the identification of the problem holistically at a systems level, but by making discrete decisions independently to solve the problem that each try to minimise the associated environmental, social and economic impact. (n=2)

The focus is on the process of solving a client's problem. A final product is produced, but it is in response to a client's problem rather than a statement of what the client needs. The problem is looked at holistically on a systems level to identify and analyse the problem. The process of solving the problem involves making decisions, but these decisions are made independently from each other. These decisions each try to help solve the problem while minimising the environmental, social and economic impacts from that individual decision.

### 4. Systems Thinkers

Sustainable design is the process of solving a client's problem with a product developed by looking at both the problem and the decisions made to solve the problem holistically on a systems level, to increase the environmental, social and economic value of the solution. (n=2)

The focus is on the process of solving a client's problem holistically on a systems level. Taking this approach, the problem is identified and analysed such that in each decision that is taken to solve the problem there is an awareness of how the decision impacts the other elements of the system. A final solution is produced to address the client's problem. The process of designing this solution involves trying to increase the environmental, social and economic value of the solution considering all the decisions that are made.

### 5. Network Thinkers

Sustainable design is the process of solving a client's problem, with the understanding that it is part of a network of wider problems facing society, by making decisions holistically on a systems level that increase the environmental, social and economic value of the solution to both the client and society. (n=5)

The focus is on the process of solving a client's problem holistically on a systems level. There is a realisation though that the client's problem is part of a larger network of problems. The solution that is produced in response to the problem tries to increase the environmental, social and economic value of the solution within both the smaller problem for the client and wider network of problems for society. This is done by considering how each decision impacts other parts of the system, and the wider network of problems.

### 6. Way of Lifers

Sustainable design is a way of life that embraces solving any problem, professional or personal, with the understanding that it is part of a network of wider problems facing society, by making decisions holistically on a systems level that increase the environmental, social and economic value of the solution to all. (n=6)

The focus is on sustainable design as a way of life that permeates all the decisions the designer makes. There is no separation between work done as a professional designer or as a person. The core process is that of solving problems to facilitate this way of life. The problems solved may be provided by a client, but they are solved to increase the environmental, social and economic value of the solution more for the wider society than for the client.