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Industry Experiences Of Environmentally Conscious Design Integration: An Exploratory Study

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abstract

This research has explored environmentally conscious design in the electrical/electronics industry sector. In this new and rapidly evolving field, existing research has not yet sought to understand the causes of success and the problems experienced when companies have integrated environmental considerations into the design process.

In the context of advanced practitioners of environmentally conscious design in the Western European and North American electrical/electronics industry sector, it is shown that:

- the timing of environmental decisions in the design process is key to environmentally conscious design;
- the environmental profile of a product is affected the most in the very early stages of the design process, particularly in the pre-specification stage, where tools for environmentally conscious design decision-making are lacking;
- an enthusiastic approach, driven by an environmental champion, is key to environmentally conscious design;
- top management commitment is important for successful environmentally conscious design;
- there is a common sequence of events that many companies go through when integrating environmentally conscious design into their product development processes. This starts with motivation, leading to widening communication and information flows and finally to whole-life thinking.

These findings emerged from one in-depth study and a transatlantic industry survey, interviewing twenty four practitioners. A framework of factors affecting environmentally conscious design was derived from this research and a model of environmentally conscious design integration developed which describes the industry's experience of integrating environmental considerations into the design processes.

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author profile

The author became interested in environmentally conscious design during his time at The Manchester Metropolitan University. He graduated in 1993 with a 2:1 Honours in Mechanical Engineering.

After the completion of his degree the author carried out a short-term environmental research contract for BT, before taking up his present post at Cranfield. Since working at Cranfield the author has been in professional contact with many companies in the electrical/electronics industry sector, carrying out research into the strategic issues surrounding environmental decision-making.

The author has spent the past three years working on an EPSRC funded research project, entitled DEEDS (DEsign for the Environment Decision Support) working closely with two leading UK electrical/electronics manufacturing organisations.

The author is a member of the IMechE and founder member/co-ordinator of the *eco2* forum; an interdisciplinary research network for researchers into ecologically and economically sound design and manufacture. This forum allows researchers to meet on an informal and informative basis and share ideas into the development of research issues in this area. To date the forum has fifty members from the UK and Europe.

Throughout his research the author has organised and run a number of workshops in the area of environmentally conscious design and has co-authored ten research publications.

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contents

APPENDICES

figures and tables

Index of figures

Index of tables

chapter 1
introduction

This chapter introduces the research presented in this thesis, highlighting the areas about which the research was centred and describing the thesis structure. The research explores, establishes and categorises the key enablers for environmentally conscious design. The study is focused on the electrical/electronics industry sector and provides a model of environmentally conscious design integration for that industry.

1.1. Focus of thesis

The electrical/electronics industry has been an area of substantial growth in the last quarter of the twentieth century. The sale of electrical/electronics goods grew in the UK by 23% in the period between 1990 and 1996 [1]. The electronics industry is set to grow by a further 73% in the next five years [2]. In the United States of America, the electronics industry is the largest employer, providing jobs to more people than the automotive, aerospace and steel industries combined [3]. This industry sector has been subjected to increasing pressure to consider environmental issues in recent years. Until now public policy has focused mainly on industrial waste streams and end-of-pipe problems and paid little or no attention to the design and development stage of a product's life-cycle. Proposed German legislation concerning electrical and electronic waste [4] states that manufacturers will have to take back their products at the end of their lives, and be responsible for the costs associated with the collection, recycling and disposal of used electronic appliances. The UK Government has stated in the past that its preferred option concerning electronic waste is to let market forces encourage product take-back. However the Government has admitted that if producer responsibility does not occur, then it may consider legislation [5]. In parallel to this some form of legislation may arise from the European Commission, which could be very similar to that proposed in Germany.

As take-back legislation increasingly places responsibility for product end-of-life (EOL) on the manufacturer, companies now have direct incentives to design products that are recyclable in order to reduce the costs of landfill disposal. Design can therefore play a key role in reducing the costs of recycling; product designers are in a powerful position within the product development process and through design have an unrivalled opportunity to address environmental issues.

The electrical/electronics industry sector has been highlighted as an area of great environmental concern world-wide; as such electrical & electronic waste has been classified as a priority waste-stream in Europe [6]. In response to this, companies have begun to consider the environment in their design processes.

This thesis draws together existing experience from literature about what constitutes environmentally conscious design; and new experiences about how environmentally conscious design has been carried out to date, taken from a transatlantic interview survey of the electrical/electronics industry sector. From the literature it will be seen that there is a need to pay particular attention to the industry transition from design to *environmentally conscious* design. This research results in a set of observations representative of the electrical/electronic industry's integration of environmental considerations into design.

Given the immaturity of the field it is not surprising that most models and methods are an extension of models and methods developed for other purposes. This thesis accepts the challenge of creating a model which can cope with the many unusual characteristics of environmentally conscious design.

By drawing on a company case study and a series of interviews with designers and design management from the electrical/electronics industry, the thesis seeks to investigate the implementation of environmentally conscious design within the electrical/electronics industry sector. This qualitative approach to the subject will result in a model which describes a framework of factors that have an affect upon the integration of environmental considerations into design, structured in a manner that shows a progression from one state of 'design' to another of '*environmentally conscious* design'.

1.2. Background

The research documented in this thesis focuses on the design process and how environmental considerations are brought into it, within the electrical/electronics industry. This section aims at placing the research within the framework of design theory and also introduces the subject of environmentally conscious design.

1.2.1. Design

The evidence that mankind has been designing goes back many ages. The art of crafting a product out of the need for a function has been practised since mankind first saw the need to use tools for survival. It is not until recently however, that this art has been questioned and attempts have been made to understand design. In this age of industrialisation, mass consumerism and increased competition theorists have begun to try and embody design, in an attempt to understand and codify it. The aims of such research are not only to ensure the ability to create products that are cheaper to make and faster to the marketplace, but also to provide an efficient framework for the inclusion of new criteria to the design process.

1.2.1.1. Design theory

There is much established research and thus literature around the subject of design theory. This thesis does not attempt to challenge, nor add to this work, but to use this understanding as a basis upon which to consider environmental criteria. The work of Pugh [7], Pahl and Beitz [8] and Cross [9] lays out a number of frameworks for design, describing the formation of a product around four main phases, stated by French [10] as being:

- analysis of problem;
- conceptual design;
- embodiment;
- detailing.

Cross interprets these four high-level activities as is shown in Figure 1:

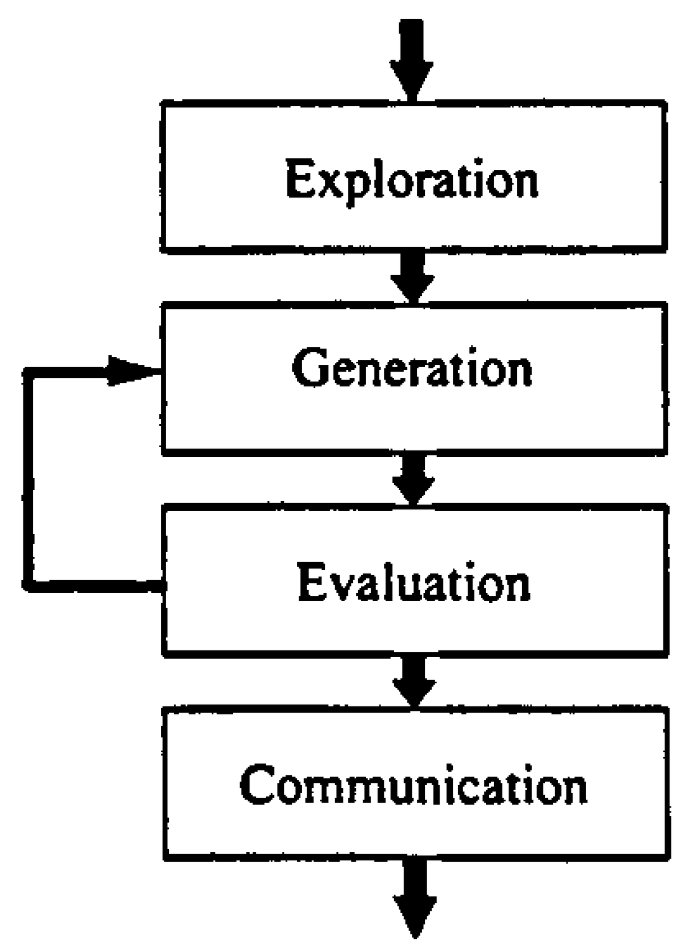

Figure 1 - Cross's simple four stage design model [9]

The types of theoretical design model vary from *descriptive* models of design, such as the one described by Cross, to *prescriptive* models of design, where a suggested pattern of design activities is proposed, rather than merely observed. Many prescriptive models of design tend to follow Cross' four stage model in a relatively linear fashion. March [11], however, focuses on the rational design process of 'production - deduction - induction'. By taking one step beyond the majority of other design models, which are often criticised for being problem-based, March focuses on a solutions-based approach to design. From philosophy, March derives that deduction is proving something that *must* be; induction something that *actually* is; whereas production is merely a suggestion of something that *may* be. The resulting design model is less a linear sequence of events than an iterative consideration of the activities of production - deduction - induction.

1.2.1.2. Design practice

In practice designers follow a less structured model than outlined by the likes of Pahl and Beitz [8] or Pugh [7]. Companies often have a formalised gate review process which stipulates the design activities and goals for each phase, and assigns responsibility for the completion of each gate review phase. Each phase of design has to be signed-off in a gate review by management before the next phase can be tackled, but inside of each gate review phase, design activities tend to be fluid in their chronology. Gate review processes classically divide the product design process into the four phases of Specification, Concept Analysis, Concept Design, and Design Analysis, after which point the final design is released to be manufactured.

As the practical design process develops, decisions that were made earlier in design become more difficult to alter. It is therefore important to get the early stages of design right because decisions made here have a more profound affect on the final form of the product. Andreasen and Hein [12] and Smith and Reinertsen [13] state that the very early stages of the design process often see 70-80% of the design and manufacturing features, and thus costs being determined.

1.2.2. Environmental considerations

It is possible to look back into history and find literature reporting environmental decisions being made as far as 300 years ago.

1661	John Evelyn writes "Fumifugium, or the Inconvenience of the Aer and Smoake of London Dissipated" to propose remedies for London's air pollution problem.
1681	William Penn requires Pennsylvania settlers to preserve one acre of trees for every five acres cleared.
1762	Philadelphia committee led by Benjamin Franklin attempts to regulate waste disposal and water pollution.
1823	James Fenimore Cooper writes The Pioneers, which contains the idea that humans should "govern the resources of nature by certain principles in order to conserve them."
1863	George Perkins Marsh writes "Man and Nature: The Earth as Modified by Human Action", with emphasis on forest preservation and soil and water conservation.

Table 1- Selected excerpts from Kovarik's Environmental History Timeline [14])

It is not until recently however, that we have been able to look back and interpret these decisions as falling under the umbrella of 'environment'. The real beginning, or 'first wave' of environmentalism is cited by Madge [15] as being in the late 1960's and early 1970's. This era of environmentalism was led by highly committed believers in the cause; people who were prepared to risk their reputation with the authorities to support the work of then-outlawed organisations such as Greenpeace and Friends of the Earth. Due to this zealous commitment, such environmental followers were often branded as over-emotional fanatics and so not taken seriously by society in general. By the 1980's 'the environment' became a small but increasing part of governments' agendas world-wide. With increasing scientific evidence of global warming, ozone depletion, acid rain and so forth, 1987 saw a gathering of the World Commission on Environment and Development in Rio, where a report, now commonly referred to as 'The Bruntland Report' [16] was created. As well as setting certain guidelines for a world clean-up, the Bruntland report laid down a definition for the term '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."[16]

The 1980's were also an opportune time for the environmental cause; the Western world was enjoying an economic boom and consumers could afford to pay more for goods that were labelled 'environmentally friendly', or 'green'. The demand for environmentally sound products was finally established. When the recession of the early 1990's arrived, consumers were no longer able to pay extra for goods that were labelled as being environmentally sound, but began to question why they should even be expected to pay a premium. It was then that industry had to begin to come to terms with the need to consider economy as well as ecology.

By now, initiatives such as the Bruntland report and ever increasing evidence from research meant that legislation and guidelines began to emerge, banning the use of such ozone depleting substances as CFC's [17] and encouraging the production of recyclable products and packaging [18]. The actions of organisations began to be greatly limited by legislation, consumer actions and by competition, because *"society will no longer allow business to adopt its traditional and cavalier attitude to the environment"* [19].

The electrical/electronics industry is a sector where a great deal of attention is being paid in terms of environmental performance, by both governments and industry itself. Existing and emerging legislation is affecting the way in which electrical/electronic products are conceived, designed, manufactured and dealt with at their end-of-life.

With the increasing demand on industry to produce environmentally better products at lower costs, the early 1990's and onwards have seen an increasing amount of activity in companies and research around the subject of environmentally conscious design or Design For the Environment (DFE) as it is also known. This has opened up a great deal of issues about how to design and manufacture a product with minimal negative impact on the environment, and with it a host of new tools and techniques [20] have begun to emerge. Academia and industry alike (and sometimes in partnership) have spent much effort on creating these tools and techniques to solve specific environmental design problems; analysed the comparative environmental affects of alternative materials; and provided environmental priorities for product designs. To date however, little attention has been paid to the way in which the environmental tools and techniques should be integrated into the design process, nor to the question of whether there should be procedures for companies to follow when first beginning to implement this environmental thinking.

1.3. Problem statement

Environmental considerations are being adopted in the electrical/electronics industry and have been so for up to five years. The design process is increasingly understood as being the earliest and best opportunity to affect the environmental performance of a product; however, we are still at a stage where there is no structured approach to incorporating environmental considerations into design. Literature exists in the areas of design theory, emerging environmental awareness, and environmental design tools, but there is little evidence of documentation about how these environmental design tools should be incorporated into design.

> Research is necessary to discover what is presently happening in the electrical/electronics industry in terms of the successes and problems experienced when integrating environmental considerations into the design process. This research should develop an understanding of the transition from design to environmentally conscious design.

The results of this research should be made available to others, so to aid the understanding of where and when to incorporate environmental considerations into the design process.

This thesis does not seek to understand environmentally conscious design in direct comparison to a classical design process, as depicted in the top representation in Figure 2 - nor does it try to predict what environmentally conscious design should look like, as is suggested by the bottom representation. Instead, this thesis concentrates on the physical design process, and by talking to practising designers and others, builds a catalogue of single actions taken towards environmentally conscious design that, when brought together, form a picture of the electrical/electronics industry's transition from design to environmentally conscious design.

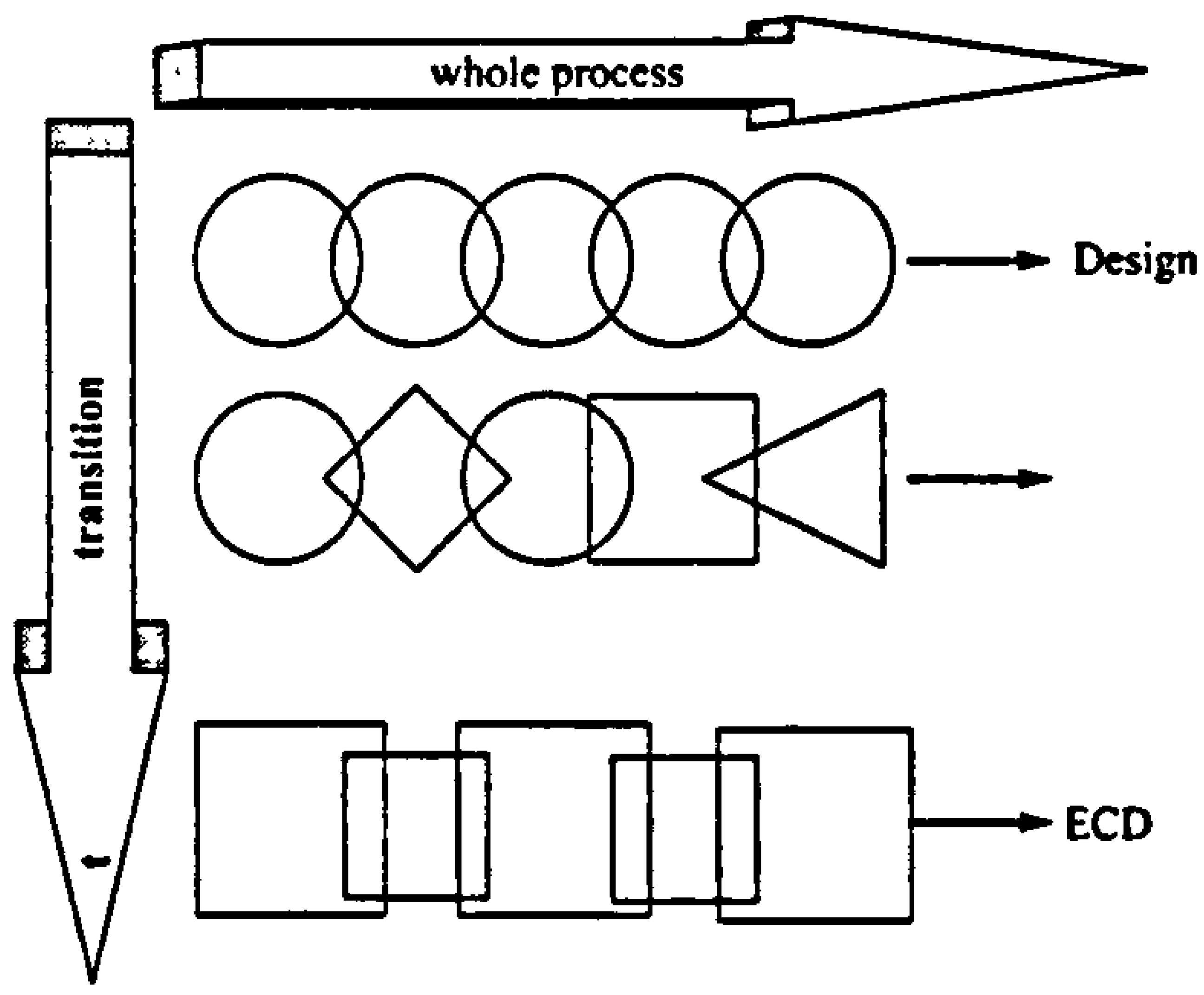

Figure 2 - Design & environmentally conscious design

1.4. Research objectives

In this thesis the author sets out to achieve the following objectives:

- identify the issues facing the electrical/electronics industry sector, in Western Europe and North America, when attempting to integrate environmentally conscious design into their product development processes;
- explain the integration of environmentally conscious design in the electrical/electronics industry sector, by building a model that will describe the transition from design to environmentally conscious design.

1.5. Deliverables

The thesis aims to provide the following deliverables in the context of the electrical/electronics industry:

- a list of lessons learned from industry about the integration of environmentally conscious design practices, based upon a transatlantic interview study;
- a model of environmentally conscious design integration which will:
    - aid the understanding of where and when to integrate environmental considerations into the design process;

- describe the transition that companies undertake in moving from design to environmentally conscious design.

1.6. Thesis structure

This thesis is set in the domain of environmentally conscious design in the electrical/electronics industry. As such, it was decided to design the research and structure this thesis to follow the four phases of design, highlighted in Figure 1. The structure for the remainder of this thesis is explained in Figure 3.

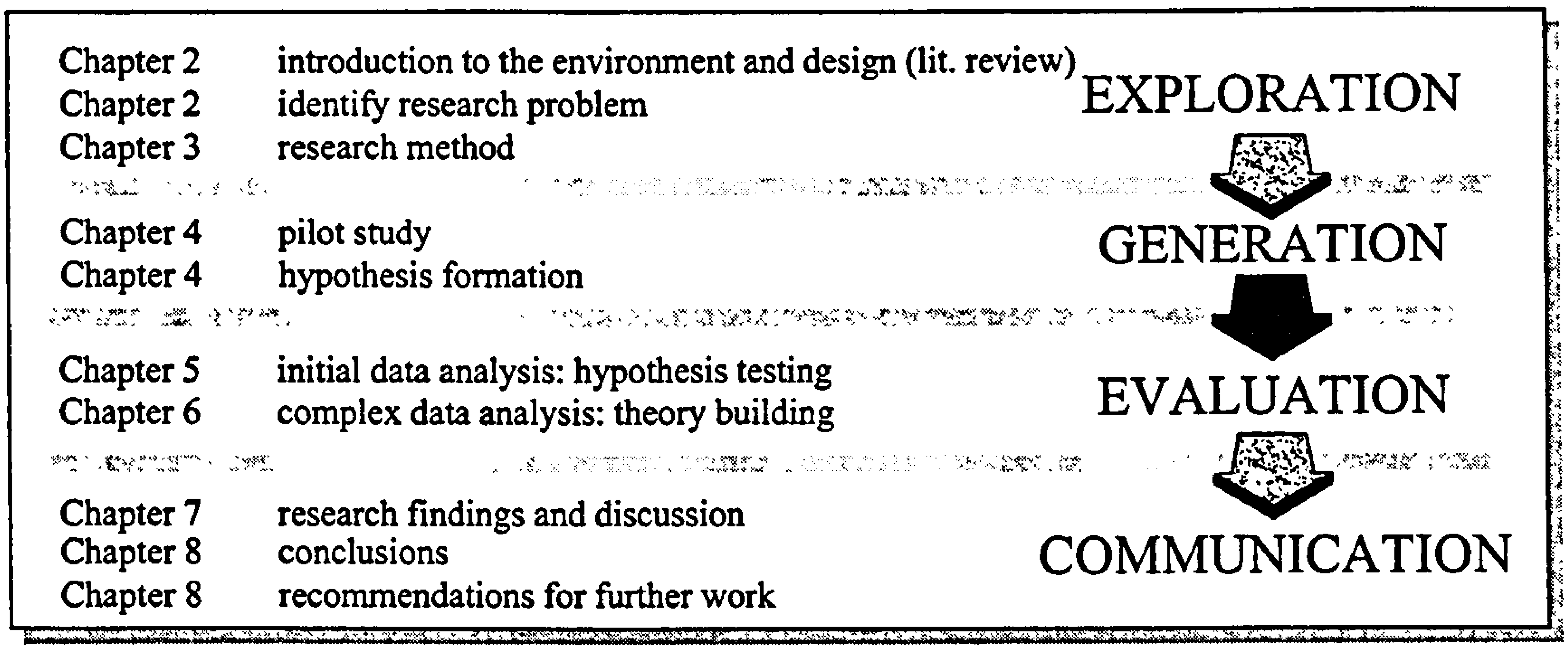

Figure 3 - Thesis structure

The four phases of the thesis are as follows:

- the **exploration** phase of the thesis introduces the research area, sets the context of the research, identifies the research problem, and develops a research method to explore the research problem.
- the **generation** phase of the research focuses firstly on defining a set of hypotheses, based on the results of a pilot study.
- the **evaluation** phase of the thesis describes the data generated from a series of interviews with designers and design management from seventeen companies in the electrical/electronics industry sector based in the UK, central Europe and the USA - these data are used to test the hypotheses in the initial data analysis. The results from the initial data analysis are then taken a step further and a theory is built of environmentally conscious design integration for the electrical/electronics industry. A model describes this theory.
- the **communication** phase of the thesis discusses the findings from the research and presents the final conclusions of the thesis. Finally areas for future research are discussed.

chapter 2

literature review

This chapter explores the literature surrounding the subject of environmentally conscious design and follows its development over the past years. Starting by investigating the root causes for electrical/electronics manufacturers to consider the environmental implications of their designs, through to the development of environmentally conscious design philosophies and techniques, an understanding will be demonstrated of what constitutes state-of-the-art in the field. With environmentally conscious design being such a new and broad field, research has developed without always agreeing a recognised set of terms; this chapter therefore provides definitions for the terminology surrounding environmentally conscious design, which will be used for the duration of the thesis. Finally the chapter aims to identify the areas where research is still required to further the understanding of environmentally conscious design in this industry sector. The areas identified by the literature review will form the basis of the need for the research that is presented in this thesis.

2.1. Mankind and the environment

Mankind has been designing products for many ages; stone-age tools provide clear evidence of man's ability to craft a product out of the need for a function. As the human race has developed we have begun to enjoy many benefits from our ever increased ability to find solutions to our needs. It is only recently, however, that we are becoming aware of the affect that our consumption is having on the environment, and that many of the materials that we are using are not of an infinite source. In the last thirty years an emergency has started to arise, as the world's population continues to increase at exponential rates and so place more demands on the world's ever diminishing resource. Ponting [21] describes some of these problems and puts into perspective mankind's increasing affect on the environment:

"By the 1980's the earth had to support about ninety million extra people every year - an increment the same size as the total population only 2,500 years ago. These people have had to be fed, accommodated, clothed and provided (to a varying extent) with goods and services. Even if per capita consumption had not increased, this huge rise in numbers was bound to place increasing demands on the earth's resources. Most of these demands were driven by basic human needs." (Ponting [21], page 394)

Basic human needs are still a scarce hope in many parts of the world, but in the wealthy West we have long since fulfilled our basic human needs and are now concentrating on richly fulfilling our desires too. Increased consumption has become a fact of life in recent years, and as the world develops by population growth and by following a Western ideal of living standards we must expect a further increased consumption of products world-wide. Bonsiepe [22] raises some of these issues and contemplates what might be necessary to change this situation:

"The irrefutable evidence of environmental deterioration puts into question the proper paradigm of industrialisation as the miracle drug of universal happiness and wealth" ... "Environmental concerns and design are intrinsically linked. We can speculate about ecological virtues. Perhaps one new virtue is parsimony. Perhaps a new powerful discourse will grow over the next years, which might result in parsimonious design because the policy of 'more of the same' might well exceed the thresholds of our dynamic ecosystem." (Bonsiepe [22])

The recognition of these issues has built up over recent years and pressures have slowly gathered momentum to keep the attention of policy makers.

2.1.1. A brief history of world environmental issues

The late 1960's and early 1970's saw the 'first wave of environmentalism', as described by Madge [15]. The seeds had been sewn for this first wave by Carson in 1962, with her book 'Silent Spring' [23], pointing out environmental disasters to the world. But public awareness reached a high in the early 1970's, around the time of the United Nations Conference on the Human Environment, held in Stockholm in 1972 [24]. Perhaps the most prominent individual in the design community around this time was Victor Papanek. In his book, 'Design For The Real World', Papanek [25] questioned the role of the designer as the catalyst to socially irresponsible products and suggested that designers have a strong moral responsibility to provide more useful service through their product designs. This book was hard on designers and won him few allies in the established design community of the 1970's, but gained widespread acceptance by young design students of the time, and ever since [15].

This first wave of environmentalism was followed by a long spell of quiet. The consumerist and affluent early 1980's led to much improvement in western lifestyles, but to the detriment of the environment, due to the emergence of a throw-away society. Since the Stockholm United Nations Conference on the Human Environment in 1972, many national environment policies had been established and globally, the United Nations Environment Programme (UNEP) was founded to encourage positive environmental action. A review in 1982 of the Stockholm conference concluded that little had been actioned in terms of the environment and world development, (the conference's chief outputs had been focused on the issues of human improvements,) and so a year later the UN General Assembly established the World Commission of Environment and Development (WCED), headed up by Gro Harlem Bruntland, the Norwegian Prime Minister of the time. WCED's mission was to, *"re-examine the critical issues of environment and development, and to formulate innovative, concrete and realistic proposals to deal with them"* [26]. Four years later, in 1987, WCED published their report, entitled 'Our Common Future', later to be known more commonly as 'The Bruntland Report' [26]. This significant report marks the period that Madge describes as, 'the second wave of environmentalism' [15], the wave in which environmental knowledge and enthusiasm appeared to stick; the public could afford to influence; and industry began to realise the effects that this commitment was going to have.

The Bruntland Report was published in the height of the 1980's period of environmental consumerism, during which products were marketed as being 'green'. Likewise, consumers began to exercise their purchasing power to demand products that were manufactured with more consideration for the environment and so manufacturers began to be affected by both the customer and the legislator:

"One finding of consumer research suggests that significant environmental conflicts raise issues of concern which are later translated into demands for action, including changes to production and to products and services." (Ryan et al [27])

In 1992, The Rio Summit was held in Rio de Janeiro, Brazil. Chosen as a significant date, being twenty years after the Stockholm conference, The Earth Summit [28], (as it was later named,) resulted in five main agreements being made. These (as reported by Grubb et al [29]) were:

- **the framework convention on climate change**, agreeing that developed countries should reduce their affect on climate change, help developing countries to do the same, return greenhouse gas emissions to 1990 levels by the year 2000, and to report on a governmental level about each country's progress;
- **the convention on biological diversity**, agreeing to terms for the use of biological resources and technology, and to preserve the biodiversity of the planet by protecting species and ecosystems;
- **Agenda 21**, providing for a bottom-up approach to 'sustainable development' (this term is explored later in the chapter) by promoting a community (local authority) based approach to reducing harm to the environment - the catch phrase for Agenda 21 has become *'think globally, act locally'*;
- **the Rio declaration**, which is a set of principles to guide action on the environment and development, operationalising the Bruntland report, but with no firm commitments;
- **the forest principles**, which is a half-way agreement to a failed convention on forests, agreeing the right to exploit forests, but with guiding principles about forest protection and management.

The Earth Summit was viewed by some to be a failure because it lacked concrete targets, but most hailed it a success, due to the mere fact that it managed to generate a large amount of consensus world-wide on an extremely complex set of issues. Despite argument over the perceived success of The Earth Summit, there has been a steadily increasing amount of industrial awareness and academic research dedicated to the minimisation of mankind's harm to the environment throughout the 1990's, as the remainder of this chapter describes.

2.1.2. Motivation for industry to act

The motivation for industry to conform to steady environmental improvement, and to be seen to be environmentally aware appears to be threefold:

1. **legislation** - industry has been, and continues to be affected by increasing amounts of legislation, ranging from: the introduction of packaging laws in Germany in 1991 [18]; to the phasing-out of ozone-depleting gases such as CFC's, starting in 1992 [17]; to the introduction of a landfill levy in the UK in 1995 [30]; to the possible introduction of product liability laws in the EU [31].

   "Increasing public concern has led to demands for more legislation to control industrial activity. The extent of legislation varies considerably between countries, and even within parts of a country, but there is universal belief that the amount of legislation will increase" ... "Meeting new legislative demands such as these will require significant changes in some industries, and will change priorities especially in areas such as product design." (MacKenzie [32])

   With respect to the industry sector under investigation in this thesis, in 1991 the European Union proclaimed electrical/electronic waste to be a 'priority waste-stream', a term meaning that it is under close consideration for legislation [6].

2. **competition** - in certain industry sectors it is seen that as one company manages to improve the environmental performance of their product, their competitor tries to further improve the performance of theirs:

   "Moreover firms are becoming aware of the potential link between technological dynamism, economic success and better environmental performance." (Berkhout [33])

   The car industry is a good example of this; Porter and van der Linde [34] report about the way in which car companies world-wide reacted to new tighter fuel consumption standards. German and Japanese car manufacturers responded to these tight fuel consumption standards by making lighter and more efficient cars, whereas the US car industry fought the standards, before eventually having to surrender and begin to redesign. By this time, however, the US car industry had lost billions of dollars to its leaner competitors. In a report by The Open University [35] 50% of the companies surveyed confirmed that their 'green' products were more competitive than their non-environmentally designed predecessors.

3. **consumer pressure** - in the late 1980's the voice of the customer began to have an effect on the environmental profile of the products they bought. Whereas in the late 1980's and early 1990's the consumer was prepared to pay a premium for 'green' goods (as reported by the US OTA [36]), the now more environmentally aware consumer of the late 1990's is beginning to expect products to have a lower impact on the environment as an inherent product quality feature, as described by Ryan et al [27].

Whatever the motivation, industry has needed help in improving the environmental performance of their products and processes and has begun to call on academia for assistance. In turn, academia has been preparing to help industry, and has spent the past years developing an understanding of where to frame environmental concerns.

2.1.3. Reflection

Increasing amounts of pressure from legislation, competition and consumers have meant that companies have begun to consider the environmental implications of their actions. By having to conform to emerging legislation and to second-guess future legislation, companies are operating to tighter standards than ever before. Environmental issues are becoming an area where companies are seeing an opportunity to compete with each other. By preparing themselves for tougher legislation a few proactive companies have gained a head-start over those who adopt a wait-and-see attitude. Environmental standards such as eco-labels are also ways in which companies are beginning to differentiate themselves from their competitors. Consumer pressures continue to drive companies to improve the environmental performance of the products they manufacture. The past decade has seen a maturing of consumer environmental awareness, to a point where environmental superiority is now expected in products, but at no extra cost.

There is a growing need for industry to consider the environmental impact of the products it designs and manufactures.

2.2. The product life-cycle

Whilst developing a framework in which to position environmental concerns the product life-cycle view has been a popular model. The product life-cycle has been represented in many ways, but the definition that carries the most authority is that of the Society of Environmental Toxicology and Chemistry (SETAC), the world-leading life-cycle analysis (LCA) authority. SETAC's representation of the product life-cycle is shown in Figure 4. The life-cycle of a product is understood to be the stages that the product goes through from conception through embodiment and use, and finally to disposal - or 'from cradle to grave'.

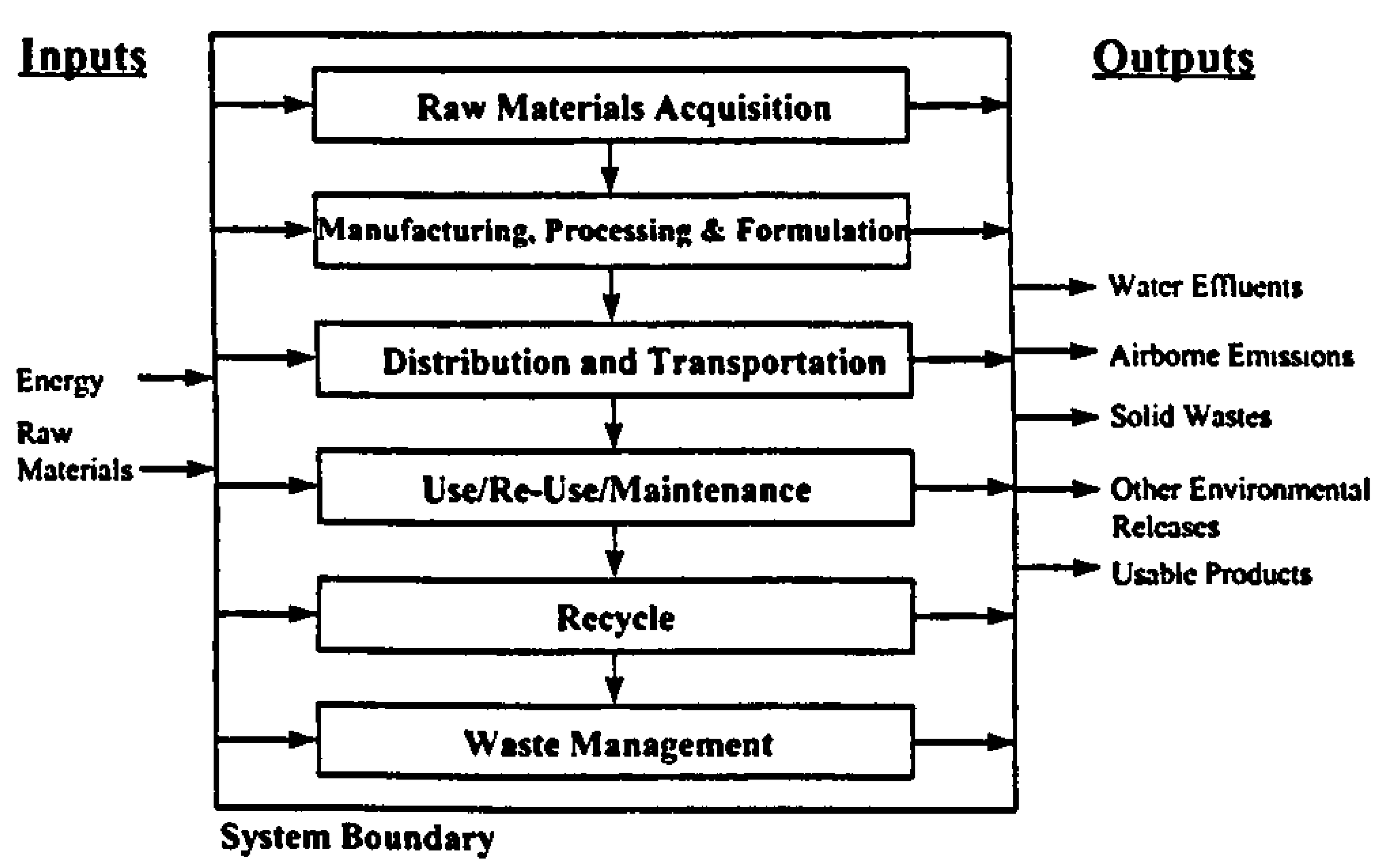

Figure 4 - Product life-cycle according to SETAC [37]

Much research over the past decade has focused on reducing the impact of the product throughout this life-cycle and has also focused on attempting to ensure that the product life-cycle be re-iterated as many times as possible for one product (via the three R's: *reduce, reuse, recycle*) - this may explain the transformation that the term 'cradle-to-grave' has undergone into it's progressed definition of 'cradle to cradle'. In other words, in an environmentalist's Utopia a product would never reach the grave, but have all of its components reused in some form or other.

2.2.1. LCA

LCA, (also known as 'life-cycle assessment'; 'cradle-to-grave assessment'; and 'eco-balancing') is a technique used to determine the environmental impact of a product. LCA is described by Fava et al as:

"an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements." [38]

The LCA exercise includes the entire life-cycle of the product, process, or activity and consists of three main stages:

- **Life-Cycle Inventory (LCI)**, where the material/energy balance of the system around the product is drawn up, within a 'system boundary' that is defined for the product;
- **Life-Cycle Impact Analysis**, where the LCI figures are examined and prioritised into the most significant impacts for the product (considering both human and ecological concerns) and environmental performance indicators are produced;
- **Life-Cycle Improvement Analysis**, where a systematic evaluation is carried out of the short and long term needs for the product. These needs may be expressed either quantitatively or qualitatively, and can cover changes in product design, raw materials choice, consumer use and so on. This requires knowledge and expertise to interpret physical requirements from tabular results. (After SETAC [37])

The main problems with LCA have arisen so far when separate organisations have drawn different system boundaries for similar products and so have collected and analysed inconsistent types and quantities of data, leading to difficulties when attempting to compare results. Lenel comments:

"As a result of these problems, LCA's carried out to date have rarely given a clear-cut answer. Thus six Scandinavian studies on milk containers all came to different conclusions; the debate on diesel versus petrol powered cars remains unresolved; and the relative merits of steel and aluminium depend critically on the application and the amount of recycling achieved." [39]

Dewberry and Goggin provide a comprehensive set of criticisms of LCA:

- *"the need to unravel complex relationships between production systems and co-products;*
- *that the functional unit of a product needs to be normalised with regard to comparable products;*
- *differences in time-scales between products and their impact on the environment are problematic;*
- *it is a comparative rather than absolute tool therefore only very similar products can be effectively appraised;*

- *given limited understanding of the complex relationships found in ecosystems LCA can only work on a less is best type approach;*
- *that it is reactive rather than proactive and not very good at 'what if' questions;*
- *it takes as given the product and process and thus supports present product forms and the status quo in terms of production facilities and product systems; and*
- *determining which environmental issue assumes priority is framed by geographical, social and economic factors and often raises more questions than answers."* [40]

These issues leave companies unconvinced about the amount of time and effort required to carry out an LCA on a product, next to the usefulness of the results to any audience other than themselves.

Bodies such as SETAC are attempting to alleviate some of these problems by standardising issues such as *where to draw the system boundary*, to make LCA's more repeatable. Another large problem in carrying out LCA has proven to be the time taken to execute it. Although this problem is also being addressed, largely by LCA consultancies and software manufacturers, who are developing off-the-shelf assessment modules, ideal solutions seem a long way off. Sweatman and Simon [41] provide a classification of environmental design tools and methods and split these broadly into two groups: analysis tools; and improvement tools. Their further concentration on analysis tools provides a list of some of the LCA tools and techniques presently available to industry.

Despite the growing interest in, and provision of LCA techniques, complex LCA is obviously not a solution for the busy product designer, who has many other design considerations to deal with. There are, however, important lessons to be learned from the theories of LCA. For this reason a number of organisations, including Motorola [42] and AT&T [43], have begun to use Abridged LCA's (ALCA) which adopt what is known as a 'quick and dirty' environmental analysis to a product design.

"At the early conceptual stages of product design the traditional LCA is not possible. Few of the materials have been specified and the trade-offs are not known because the product as a whole is undetermined. This has raised a catch-22 where an LCA requires detailed knowledge of a product but the product has little detail. [Motorola] *proposes to change the way LCA is normally used and approach new product design using a tiered method, which asks questions appropriate to the stage of the design process."* (Hoffman III on Motorola's ALCA method [42])

The attempt to bring LCA's closer to the design team by providing abridged tools and relating decisions to the company's design process has resulted in the attitude that, at the design stage few details are known about the product which is being designed, and the details that are known are probably fixed anyway, making it too late to affect these. For these reasons there has been a move away from detailed numerical analysis in favour of more strategic questions, asked early in the design process. The aim of these is to affect all subsequent design decisions so that informed environmental choices can be made.

ALCA's generally assign a score to the product's environmental performance using some form of eco-point[1], which allows for comparison between other environmental design concepts. These tools appear to have been successful in the organisations that have implemented them, due to the fact that they have provided a useful aid to the designer when faced with making a quick but informed environmental decision about two possible design alternatives.

2.2.2. Life-cycle thinking

Despite the evidence found regarding LCA tools and techniques, little was discovered about the general principles of life-cycle thinking. Turning to Concurrent Engineering (CE) literature, Kannapan and Marshall [44], and Cleetus alike [45] have provided a definition of CE that extends the term to the consideration of a product throughout its life-cycle, from concept to end-of-life, and beyond:

"Concurrent Engineering, in the ideal case, brings to bear all concerns throughout the product life-cycle during product design. The strategy of concurrence provides an opportunity to address the source of conflicts between design agents representing the concerns of different engineering disciplines, functionality, marketability, manufacturability, maintainability, etc. early in the engineering process." (Kannapan & Marshall [44])

"Concurrent Engineering is a systematic approach to integrated and concurrent development of a product and its related processes, that emphasises response to customer expectations and embodies team values of co-operation, trust and sharing in such a manner that decision-making proceeds with large intervals of parallel working by all life-cycle perspectives early in the process, synchronised by comparatively brief exchanges to produce consensus." (Cleetus [45])

Looking then at design theory, many design models go only as far as manufacturing and selling the product, after which time the company's responsibility ends. This is also reported to happen in practice. Figure 5 highlights the difference between theory and practice in this area. There is little evidence of companies actually taking responsibility for their products once they have sold them - the relationship between the company and the product ends there.

[1] eco-points - a system of assigning relative environmental load units to product features to allow for comparative analysis of design alternatives.

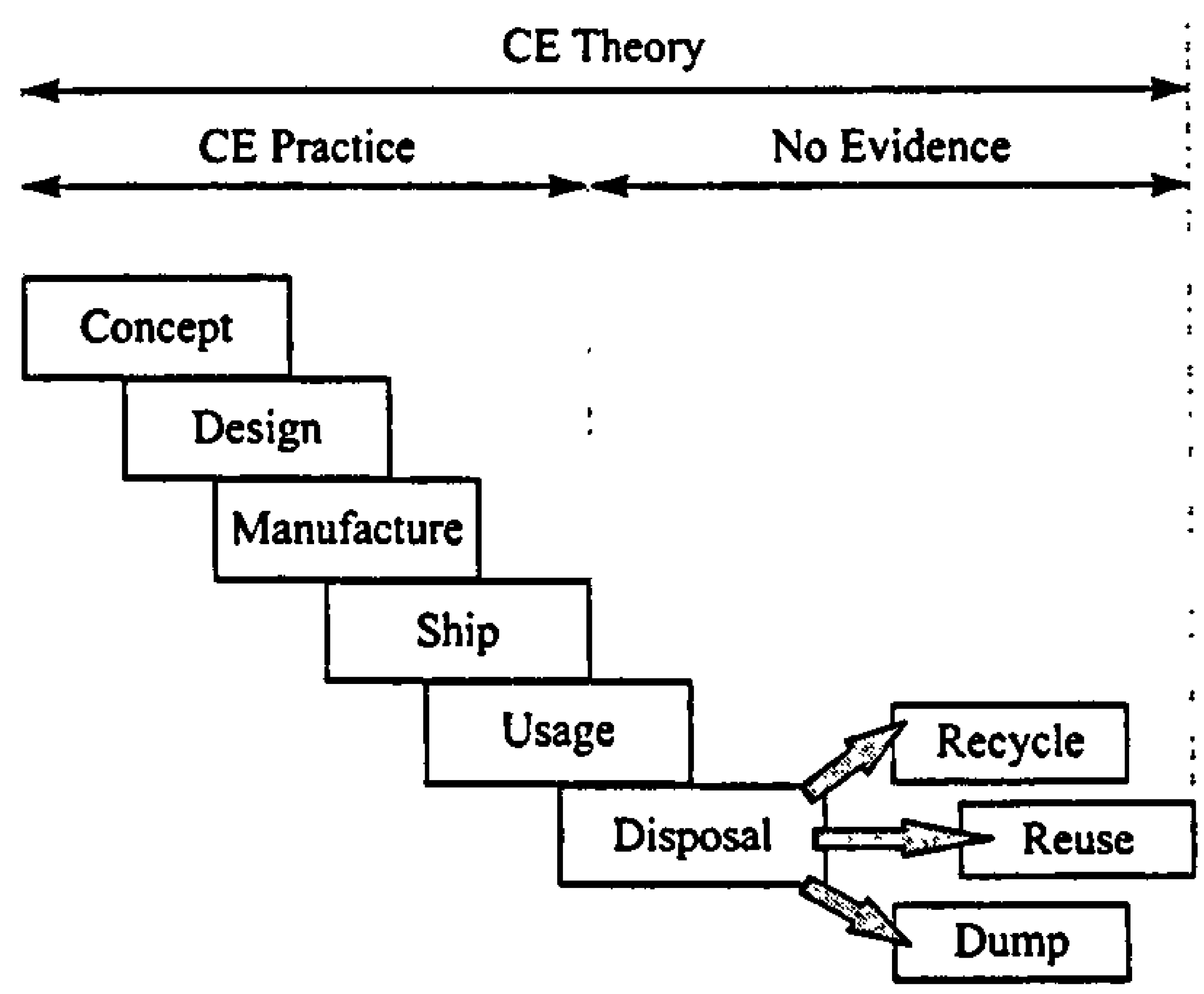

Figure 5 - The gap between theory and practice

It would therefore be difficult to expect designers to have a life-cycle philosophy without first understanding what the life-cycle of a product really entailed. Very few models of design go beyond the selling of a product to its usage, service and disposal phases, which reflects industry's traditional relationship with the products that they manufacture. If design models were used that were in line with the two statements made by Kannapan and Marshall, and Cleetus above, designers may be able to develop more of an understanding about the whole life of their products, and how the consideration of the whole life-cycle would alter the way in which they designed.

2.2.3. Reflection

A popular method of assessing the environmental impacts of a product throughout its life-time is known as LCA. LCA entails the detailed analysis of every material, energy and toxicological input and output related to a product over its life-cycle. Although a great deal of research has been carried out in this area, LCA still remains of little value to designers; it takes too long to execute and results are often difficult to interpret. Results are also very dependent on where the analyst chooses to draw the system boundary and to date, where LCA has been used to compare the environmental impact of similar products, results have been inconclusive.

There is evidence of a move towards simpler techniques to environmental product analyses known as abridged LCA's. These techniques require less time to carry out and are less data-intensive. Designers have experimented with these methods and have found their more qualitative approach useful to adopt, though with some concerns over quality of decision.

Although the adoption of a life-cycle approach to environmentally conscious design is becoming more commonplace, little evidence exists about a similar approach to product design. Whereas life-cycle analysis is a reflective view of a product's impact on the environment, life-cycle design suggests an opportunity to project environmental ideas into future designs.

> A life-cycle approach to product design is required that will aid industry in projecting environmental robustness into product designs. Abridged LCA techniques should aid the process of continuous environmental improvement.

2.3. The environment as a part of design

Over the past decades one product after the next has begun slowly to acquire features that mean the product will have a less negative affect on the environment. It is interesting and important to discover how the product design process has been altering to allow for environmental considerations to be included within it, so to gain an appreciation of the route that has been taken to get to today's definition of environmentally conscious design and to try and project to the future. A good starting point, then, would be to look at design theory.

2.3.1. The design process

As with definitions of the product life-cycle, there is no shortage of interpretations of the design process. Concepts of the design process vary.

March [11] views the rational process of design as being solutions-based rather than problem-based and describes three states of mind that designers experience when carrying out design.

Powell views the design process as being, *"as if you've seen an explosion on film run backwards very slowly. What you see is a whole load of dust and rubbish and bits and pieces all floating about in the air, and as you wind the film back it goes uuuuuwwwwwvvvvvvvump! very quickly, and the design is finished,"* (in Lloyd and Deasley [46]), emphasising the fact that design is a highly iterative and disorganised process.

Then there are models of engineering design, which break the process down into logical and sequential units, with definite goals for each stage along the way, in an attempt to organise some of Powell's chaos into manageable and repeatable phases. As this thesis deals with environmental considerations that interact with the engineering design process, whilst keeping other models of design in mind, engineering design models will be used as the main framework around which to place environmental considerations. Two models have been chosen here to illustrate the way in which engineering design is approached.

Cross's simple four-stage model [9] divides the design process into the areas of:

- **exploration**, where the need for a new product is identified, justified, and a product design specification is drawn up;
- **generation**, where many product concept ideas are created;
- **evaluation**, where these concepts are assessed for their feasibility against the product design specification, and many concepts are narrowed down to one chosen idea; and
- **communication**, where the evaluated concept ideas are developed into a final product design.

Cross's simple model (Figure 1) illustrates the typical process of engineering design. The feed-back loop shows that there are iterations between the evaluation and generation stages of the design process, to allow for unfeasible concepts to be re-worked.

At the other end of the complexity spectrum is Pugh's Total Design Activity Model, as displayed in Figure 6. The model's central core of activities are all considered to be imperative for design. The core consists of *market - product design specification - conceptual design - detail design - manufacture - sales.* The first three phases are described as follows:

*"All design starts, or should start, with a need that, when satisfied, will fit into an existing **market**, or create a market of its own. From the statement of the need - often called the brief - a **product design specification** (PDS) must be formulated - the specification of the product to be designed. Once this is established, it acts as the mantle or cloak that envelops all the subsequent stages in the design core. The PDS thus acts as a control for the total design activity because it places the boundaries on the subsequent designs. **Conceptual design** is carried out within the envelope of the PDS, and this applies to all succeeding stages until the end of the core activity."* (Pugh [47], page 5)

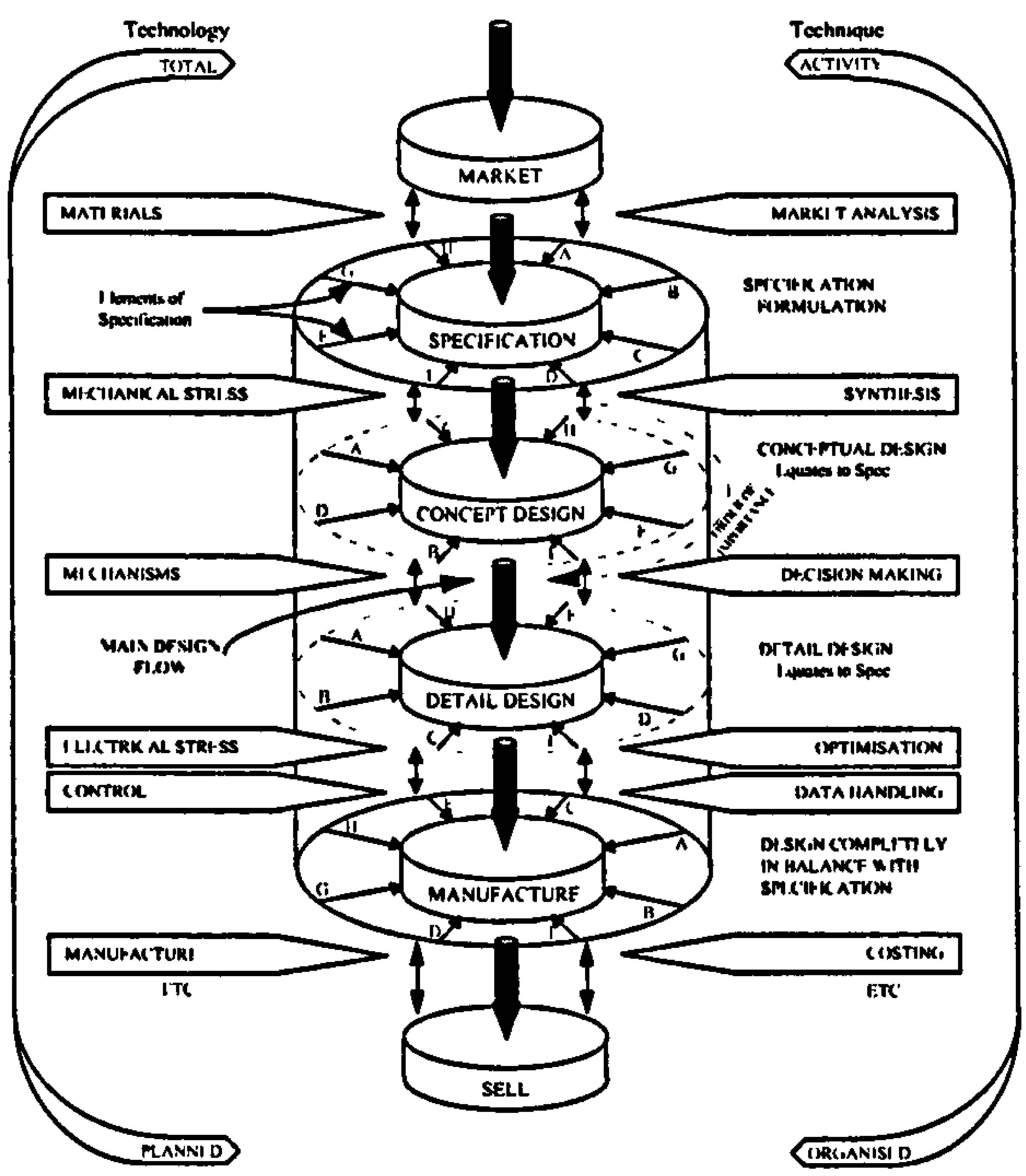

Figure 6 - Pugh's model of design [47]

Although this model (and most other engineering design models) appears in sequential flowchart form, real-life design acts in an iterative fashion. Pugh makes some allowance for this in Figure 6 by the inclusion of double-headed arrows.

"The main design flow is itself an iterative process. For example, you may have reached as far as the detail design of a product when a new concept emerges (one that can be engineered to meet the PDS). If it appears to be a highly attractive solution to meet your PDS, and time permits, you will return to the conceptual stage and possibly re-engineer the solution." (Pugh [47], page 6)

The lettered spokes linking the PDS to the design core relate to various considerations that need to be made in that stage of design. This illustrates the importance of the PDS as a catalyst to including these considerations within the product design. Examples of considerations that might be found on these spokes include: safety; testing; assembly; quality; environment; shelf-life; packaging; maintenance; weight; market constraints; disposal; size; etc. Many of these (and other) considerations are made as and when the designer encounters them during design - there is often a critical point where a decision needs to be made about, say, the way in which the product is to be assembled, before anything else can be progressed in the design. At this stage the designer may need help in making a decision about how to assemble the product, which is when an approach such as Design For Assembly (DFA) would be helpful. Many of the considerations listed above can be solved using a Design For X (DFX) approach.

2.3.2. DFX and the environment

DFX is a term that is used to represent a variety of considerations that must be made whilst designing a product. Olesen describes DFX as:

"a tool in which a long series of relationships between design characteristics have been formulated, together with their dispositional effects, measured in relation to the universal virtues. In this way the designer is given dispositional insight into the technical areas in which he does not naturally belong." [48]

The need for DFX tools arises from the fact that designers cannot be expected to be subject experts on every factor that arises during the design process. With DFA, for example, issues such as parts orientation; fastening techniques; parts-minimisation; and feeding techniques are addressed to make one specific stage of the product's life more effective [49]. Design For Disassembly (DFD) is a technique that aids the designer in considering how to do the opposite of DFA at another specific point in the product's life - the end. The point here is that DFX considerations relate to specific stages in the design process. An example of the relationship between DFX considerations and the design process is given in Figure 7.

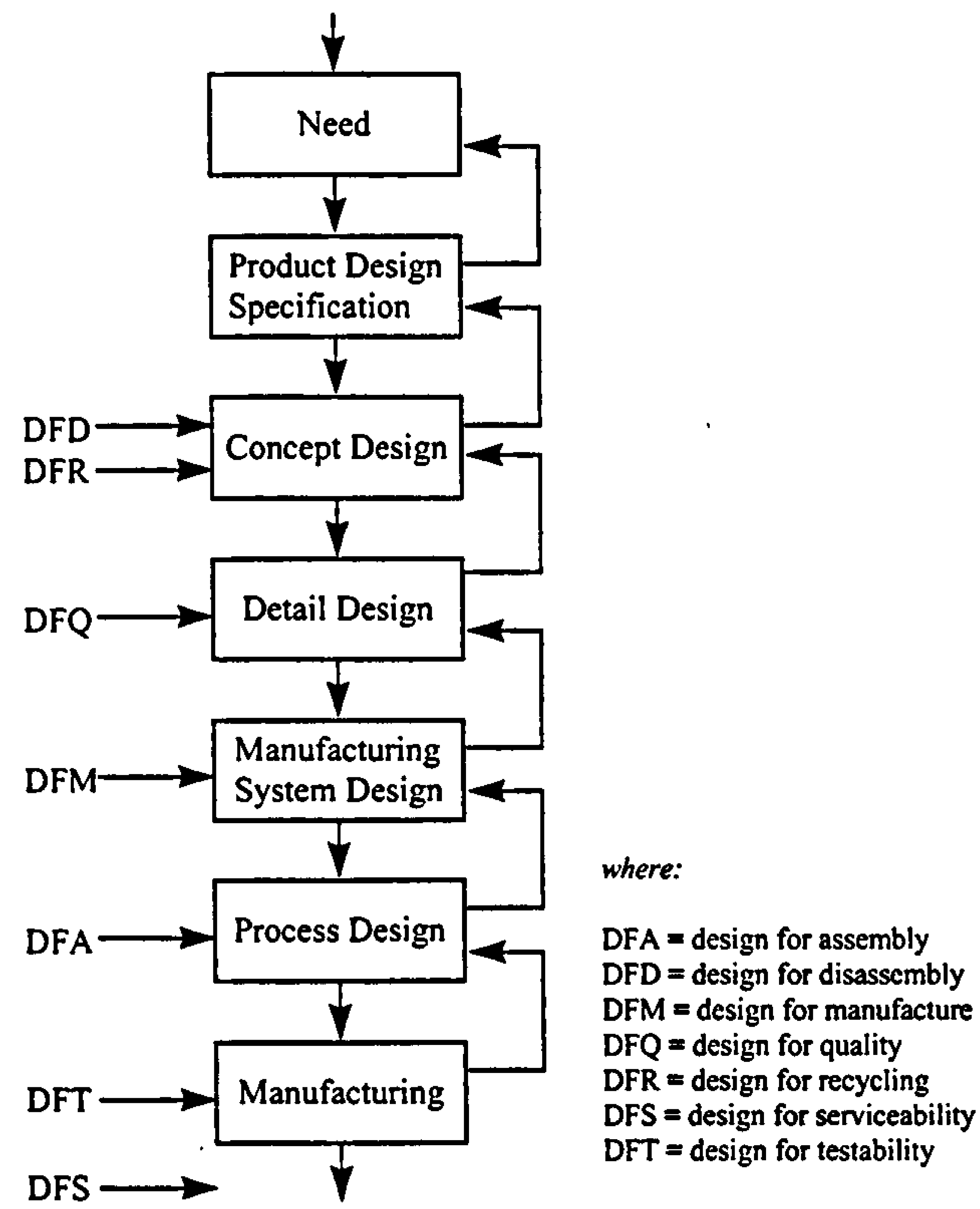

Figure 7 - DFX into design (McAloone & Holloway [50])

Olesen [48] views environmental design considerations as falling under the DFX umbrella, as can be seen with DFD and DFR in Figure 7 above. This raises the question of whether environmentally conscious design is an extension of DFX, in that existing DFX principles and methods are applicable and sufficient. For issues that occur at specific stages in design, (such as DFD and DFR), DFX may indeed be sufficient. However for other facets of environmentally conscious design such as reduction of materials; reuse of components over multiple product life-cycles; energy efficiency in design and manufacture; or the moral implications of designing the product - these affect every stage of the product's life and not merely one specific point in the design process. This makes the picture of environmentally conscious design more complex. We have reached a stage where the designer cannot any longer be expected to consider every environmental consideration in a simple step manner, but as an integral part of every stage in the design process. The next section explores the different facets of environmentally conscious design in more detail, in an attempt to understand how they fit into the design process.

2.3.3. Reflection

The product design process is often represented as a series of sequential stages, within which design decisions develop to produce a final product design. Upon this design process act various external product requirements which the product designer must consider. The traditional way to consider these external requirements has been to take a Design For X approach, where 'X' is the external requirement.

Although some environmental considerations can be treated in this manner it has become evident that environmental issues are generally much more complex than other DFX considerations; they introduce morals and ethics,; longer term considerations; and complicated goal setting. Environmental considerations also require a new set of decision-makers to be involved with design decisions. A new approach to design is required that somehow manages to synthesise these new factors.

Traditional models of design are not sufficient to fully explain the inclusion of environmentally conscious design criteria.

2.4. Environmentally conscious design definitions

The past few years have seen a growing catalogue of terms to describe the research and the techniques that are being developed to aid the consideration of environmental issues during design. This section explores these terms, so to relate them to each other and to develop an understanding of what tools and techniques exist and what is under development.

2.4.1. The DFX family

Design For Recycling (DFR) arises from the widely accepted need to reduce the amount of waste that goes to landfill and the fact that complex products contain materials that require separating before they can be recycled. Kuuva and Airila [51] provide a set of practical arguments for recycling:

- *"limited raw material resources;*
- *growing consumption causing growing volumes of waste and waste-related problems;*
- *problems in disposing of products containing hazardous or otherwise problematic waste;*
- *ceasing capacity of existing dumping areas and lack of or local opposition to new ones;*
- *increased expenses for waste handling and disposal;*
- *growing ecological awareness and trends preferring 'eco-products' in the market;*
- *national and international legislation demanding recycling and recyclability."*

Recycling is the last of the three R's - *reduce, reuse, recycle* - perhaps because:

- if it is possible to *reduce* the need for a product or material, this is the ideal situation;
- if this is not possible, as long as the product or material can be *reused* at the end of its first useful life, at least its life is prolonged;
- if neither of these are possible, the product or material should at least be *recycled.*

The threat of legislation in (largely) Germany and the rest of Europe and the recognition of potential cost savings provided the initial push towards recycling in the early 1990's. In a report for the Centre for Exploitation of Science and Technology (CEST) Roy writes:

"The electronics industry, a significant contributor to Europe's GDP, is under legislative threat. Concern with use of landfill to dispose of what is potentially

valuable, re-useable material from EOL [end-of-life] *equipment has stimulated many environmental groups to press for European legislation. Such concerns are strongest in countries with scarce land resources. Germany and Japan have already started legislative initiatives"..."most EOL equipment, containing valuable material, remains unrecycled. This untapped wealth is estimated to be annually worth £50 million in the UK alone."* [52]

Guidelines for DFR generally cover holistic design issues rather than specific ones and include issues such as:

- using recycled material;
- selecting materials that are compatible with recycling;
- designing for disassembly (DFD);
- reducing labelling on plastics (if the label adhesive is incompatible);
- reducing hazardous materials such as in cathode ray tubes or batteries;
    - making hazardous materials easy to access for removal;
- selecting recyclable packaging. (After ICER [53])

Recycling is widely accepted as being a good thing and is possibly one of the most popular environmental activities that Western society has adopted and feels good about doing. It is one of the few tangible environmental activities that society can take part in and measure. However Cooper looks in great detail at the concept of recycling and warns:

"The fact that recycling allows raw materials to be used repeatedly might appear to suggest that no environmental damage need be caused by ever-increasing consumption in industrial countries. Yet the recycling process, like all physical activities, affects the environment. Energy is consumed as waste products are collected, sorted, cleaned and separated into their constituent materials. Pollution is caused, both as a by-product of this energy consumption and, more directly, by materials reclamation processes. The subsequent manufacture and distribution of products also has an impact on the environment"..."There is a prospect that products which will malfunction will increasingly be recycled rather than repaired." [54]

A typical example here is the fact that people generally do not give a second thought to driving to a bottle bank to dispose of a month's supply of glass. In actual fact the fuel that they expend whilst driving to and from the bottle bank often far outweighs any benefits of the glass being recycled - unless the bottle bank is en-route to a regular destination for the person. It is a difficult subject to discourage people from recycling glass, because of the amount of education that has been invested in telling them that recycling is a good thing. However, it is important to educate about the wider issues that explain the correct way in which to recycle. The same thinking can be applied to DFR; if a product is designed with recycling in mind, it is important to remember that DFR should not be carried out in a vacuum, but should also allow for servicing and maintenance.

Design For Disassembly (DFD) is the main enabler to DFR and concentrates in more detail on specific design issues such as fastening types and orientation of product components. Although in many ways DFD can be viewed as the reverse of DFA, this is not entirely the case, as Brooke states:

"DFD begins with parts consolidation in the original design. It isn't necessarily the same as Design For Manufacturability and Assembly (DFMA), even though the two share reduced fastener content, easy fastener installation and self-locating components." [55]

The main differences in design thinking that DFD introduces are the facts that:

- whatever assembles well does not necessarily disassemble well; and
- the order in which a product is disassembled in the real world will have to do with the economic value available from it.

Dowie [56] presents a methodology to ensure that products can be designed to be attractive for recycling at end-of-life. This methodology comprises a set of indices that can be arranged to provide a disassembly precedence strategy for a product.

DFD methods are now available in checklist and software format and are beginning to emerge as modules for certain computer aided design software, such as described by Poyner and Simon [57].

Design For Environment (DFE) is a term that developed from DFX and means many things to many people. Just as Olesen views DFX as being an umbrella under which many considerations (including environmental) are made [48], DFE can be viewed as an umbrella for the many environmental considerations that exist in design. Van Hemel and Keldmann [58] argue that, to an extent, DFE is a part of the DFX family, this extent being the systematic way in which environmental considerations can be dealt with by the use of tools and techniques.

However, DFE is much more than the systematic application of tools and techniques at set stages in the product development process, and van Hemel and Keldmann do see DFE differing to DFX in eight main ways:

1.	"there is no DFE without morals and ethics" - meaning that DFE causes the designer to think about moral and ethical issues that do not occur in other DFX elements;
2.	"the mindset is the fundament" - meaning that the way in which the designer thinks has a profound effect on DFE, and this mindset is created by the designer themself (through personal experiences - daily occurrences, following the media etc.) Furthermore the company's corporate environmental mindset affects the designer's DFE;
3.	"setting the right goals is complicated" - meaning that other DFX's have clear and tangible targets, whereas DFE's target is to contribute to sustainable development, a term which no-one seems able to quantify;
4.	"DFE results are difficult to measure and communicate" - meaning that quantitative measures such as LCA produce results that are still under discussion, and qualitative measures are hard to attribute to environmental improvements;
5.	"both product and life-cycle are synthesised" - meaning that DFE encourages the designer to think about the environmental performance of the whole product life-cycle system and not simply the environmental performance of the single product;
6.	"external relations are essential in DFE" - meaning that because DFE considers the whole life-cycle of the product, the stakeholders of this whole life-cycle must be consulted, from the

	materials supplier to the manufacturing engineers to the actual users;
7.	"the stakeholder gallery is expanded" - meaning that DFE opens the product up to a wider group of people who will have an opinion about the environmental design of that product, including the recycling industry and consumer associations;
8.	"legislation and regulation play important roles" - meaning that legislation has a major affect on DFE - companies will not encourage their designers to make long-term environmental improvements if they feel that future legislation may not support them or, worse still may oppose these improvements.

Table 2 - How DFE differs from DFX (After van Hemel and Keldmann [58])

DFE is also known as 'Environmentally Conscious Design' (ECD); 'ecodesign'; 'green design'; 'life-cycle design'; and 'clean design'. Although these terms are largely interchangeable and have many of the same goals, some people infer differences in meaning from the different titles.

It is interesting to note some definitions of the above terms, to try and understand the perceived differences in their meanings.

Green design - *"a design process in which environmental attributes are treated as design objectives or design opportunities, rather than as constraints. A key point is that green design incorporates environmental objectives with minimum loss to product performance, useful life, or functionality."* (US Office of Technology Assessment [36])

Green - *"is passé and very much related to popular interest in the subject which emerged in the mid to late eighties. Unfortunately it sums up images of dubious advertising campaigns often portraying inaccurate or misleading information regarding a product's intrinsic 'green' value. Today its use tends to focus on single issues relating to the design of products such as considering the use of energy resources. Design for recyclability, using recycled or less toxic materials and energy efficiency for examples, are all what might be considered to be 'green' design."* (Dewberry and Goggin [40])

Ecodesign or ECD - *"design which addresses all environmental impacts of a product throughout the complete life-cycle of the product, without unduly compromising other criteria like function, quality, cost and appearance."* (ECO2-IRN [20])

Life-cycle design - *"all life-cycle phases (design, production, distribution, usage, and disposal/recycling) are considered from the beginning at the conceptual stage to ensure fulfilment of the environmental requirements."* (Alting [59])

Life-cycle design - *"draws on ideas such as concurrent development and cross-disciplinary teams. Each is needed to successfully balance environmental issues with cost, performance, culture, and legal criteria."* (Keoleian and Menerey [60])

This thesis has adopted the term 'environmentally conscious design' as a working definition.

2.4.2. Industrial ecology

Section 2.2.1 describes the system boundary that must be drawn before considering the environmental inputs and outputs that are concerned with a product. The lack of any present guidance about where to draw the system boundary for a product assessment leaves a problem of system boundaries being defined either: too narrowly, not taking any outside (but contributory) factors in to consideration; or too widely, where the earth would need to be modelled in order to achieve satisfactory results.

The research community is beginning to develop a feel for the optimal size for a system boundary and is going one step further, to consider what would happen if two or more products were considered together. Industrial ecology draws a system boundary around not one product or one organisation, but a group of organisations or systems, in an attempt to optimise the inputs and outputs between the collective group. The aim is, by mimicking nature, to ensure that one man's waste becomes the next man's raw material. Graedel and Allenby describe industrial ecology as:

"the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimise the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product and to ultimate disposal. Factors to be optimised include resources, energy and capital." [61]

They go on to explain how designers can play a part in industrial ecology by considering future uses of the products they design and ways to ensure that their products are designed with these possible uses in mind. Van der Ryn and Cowan [62] report on one such project in Kalundborg, Denmark, where an electrical power plant; an oil refinery; a pharmaceutical plant; a wallboard factory; a sulphuric acid producer; cement manufacturers; local agriculture and aquaculture; and nearby houses interact as an industrial ecosystem to share heat; water; power; minerals; and wastes (or raw materials, as they are viewed in this case). To plan for such a system obviously requires a wider set of design principles again, considering not one, but a series of product life-cycles.

2.4.3. Sustainability and sustainable development

The Bruntland Report of 1987 [26] was the major instigator of the term 'sustainable development', the way by which mankind should attempt to move towards an almost Utopian goal of sustainability, which has been described as, *"a long term and difficult goal of reaching an ecologically sustainable state."* (Dovers and Handmer [63])

2.4.3.1. Defining sustainable development

The definition of 'sustainable development' from the Bruntland Report states:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs." [26]

Further, a report produced by the UK Department of the Environment highlights just what 'sustainable development' covers. The report states that if sustainable development is to be achieved a number of media need to be addressed, ranging from human population to the global atmosphere; from air and water quality to soil and land use; from wildlife and habitats to sources of energy; from manufacturing and services to biotechnology; from transport to leisure and quality of life. In its summary report on sustainable development it is stated:

"Sustainable development does not mean having less economic development: on the contrary, a healthy economy is better able to generate the resources to meet people's needs, and new investment and environmental improvement often go hand in hand. Nor does it mean that every aspect of the present environment should be preserved at all costs. What it requires is that decisions throughout society are taken with proper regard to their environmental impact." [64]

From these two definitions alone, it is easy, to understand how a designer could get lost in thought, firstly in wondering what a 'need' is and secondly, which environmental decisions are the correct ones in terms of their affect on the whole of society. Only by honing these definitions down further can the goal of sustainability attempted, by relating the terms 'sustainability' and 'sustainable development' to the design community.

2.4.3.2. Sustainable design

Already discussed in this chapter are the techniques of engineering design; the need to consider the environmental impact of products; and issues about how to include environmental considerations into design. However Simon [65] argues that although environmentally conscious design in itself *may* promote sustainability, it is not necessarily actively aiming at sustainability. Therefore a new practice of 'sustainable design' is necessary. Sustainable design should create a sustainable product which *"must generate capital for future generations to offset its use of non-renewable resources"* [65]. Turner et al [66] divide sustainability into two:

- **weak sustainability** - which is the philosophy that all capital is capable of being substituted, so as long as we leave behind roads and infrastructure, we can continue to deplete non-renewable resources; and
- **strong sustainability** - which adopts the philosophy that there is a critical mass of natural capital that must not be substituted with mankind's creations.

They go on to classify various possible environmental positions that a designer could adopt, as seen in Table 3.

Technocentric		Ecocentric	
VERY WEAK SUSTAINABILITY	WEAK SUSTAINABILITY	STRONG SUSTAINABILITY	VERY STRONG SUSTAINABILITY
Growth oriented, resource exploitative	Resource conservationist, managerial	Resource preservationist	Extreme preservationist
Traditional ethics, rights of the individual; instrumental value to	Intragenerational and intergenerational equity; instrumental	Interests of the collective over the individual; primary value of	Interests and rights of all species and parts of the environment;

humans of nature	value to humans of nature	ecosystems	intrinsic value of nature
All new products imply progress and contribute to growth	Some products unacceptable in their effect on the environment	Product design must be directed to ensure that it meets society's needs	Many products unacceptable; reduced scale of economy, minimised use of resources

Table 3 - Designer's possible environmental viewpoints (in Simon [65], after Turner et al [66])

This begins to introduce some questions for designers and organisations to ask themselves but gives little concrete guidance about how to design, further than high level suggestions. This is the state of the art in sustainable design thinking.

2.4.4. Drawing the terms together

If we are to aid designers in making environmental decisions, it is important to understand where we stand - what is achievable now and what is a hope for tomorrow? In an attempt to provide some direction for designers about where to target their efforts in environmental design, the ECO2-IRN Forum differentiate the various philosophies (discussed so far in this chapter) from each other as follows:

DFE, DFD, DFR, LCD	all of these methods, it was argued, concentrate on single specific design issues. Each is a technique which fits into the design process at some stage, (like DFA & DFM,) acting as a milepost for environmentally conscious action. Practising all of these techniques, however, will not necessarily produce a completely environmentally sound product. Practising one, or a number of these techniques is said to be practising Green Design.
Green Design	A green design focuses on single-issues. For example, hair-spray manufacturers now claim to have green hair-sprays because they no longer contain CFC's. This is a step in the right direction, perhaps, but is not a definitive solution. A green design can contain one or a number of single actions that go towards altering the product's environmental impact.
Eco-Design/ECD	These two principles are thought to be one and the same. The difference here is that design considerations are flavoured from the very conceptual stages so that the product is developed in an environmentally conscious manner. There are not simply physical design mileposts (although these may still exist), but in Eco-Design/ECD the environment is considered inherently at each stage of the design process. This may be achieved by corporate strategy; decision-making tools; or on-line CAD tools. This fashion of design implies a shift from the original practice of cost-led design to environment-led design. (In reality, cost must still be high on the agenda, or the design would never leave the drawing board.)
ECDM	This is the progression of ECD down the design model into the manufacturing process. Design of products also affects the manufacturing process, and ECDM should consider the environmental impact of product designs on their production processes.
Sustainable Design	Taking Simon's definition [65] *"A sustainable product must generate capital for future generations to offset its use of non-renewable resources."* Sustainability is considered to be more of a direction than an action. We must always try and move towards sustainability, but never believe that we are there. How can this be interpreted into a design principle?
Sustainability	This is seen as being the ultimate goal; everything we consume goes complete circle, is renewable and has a further use. This is seen as being the boundary within which sustainable design fits.

Table 4 - Differentiation of environmental design philosophies by ECO2-IRN [20]

Having differentiated these terms, the Forum represents them graphically, this time attempting to relate them to each other, as Figure 8 shows.

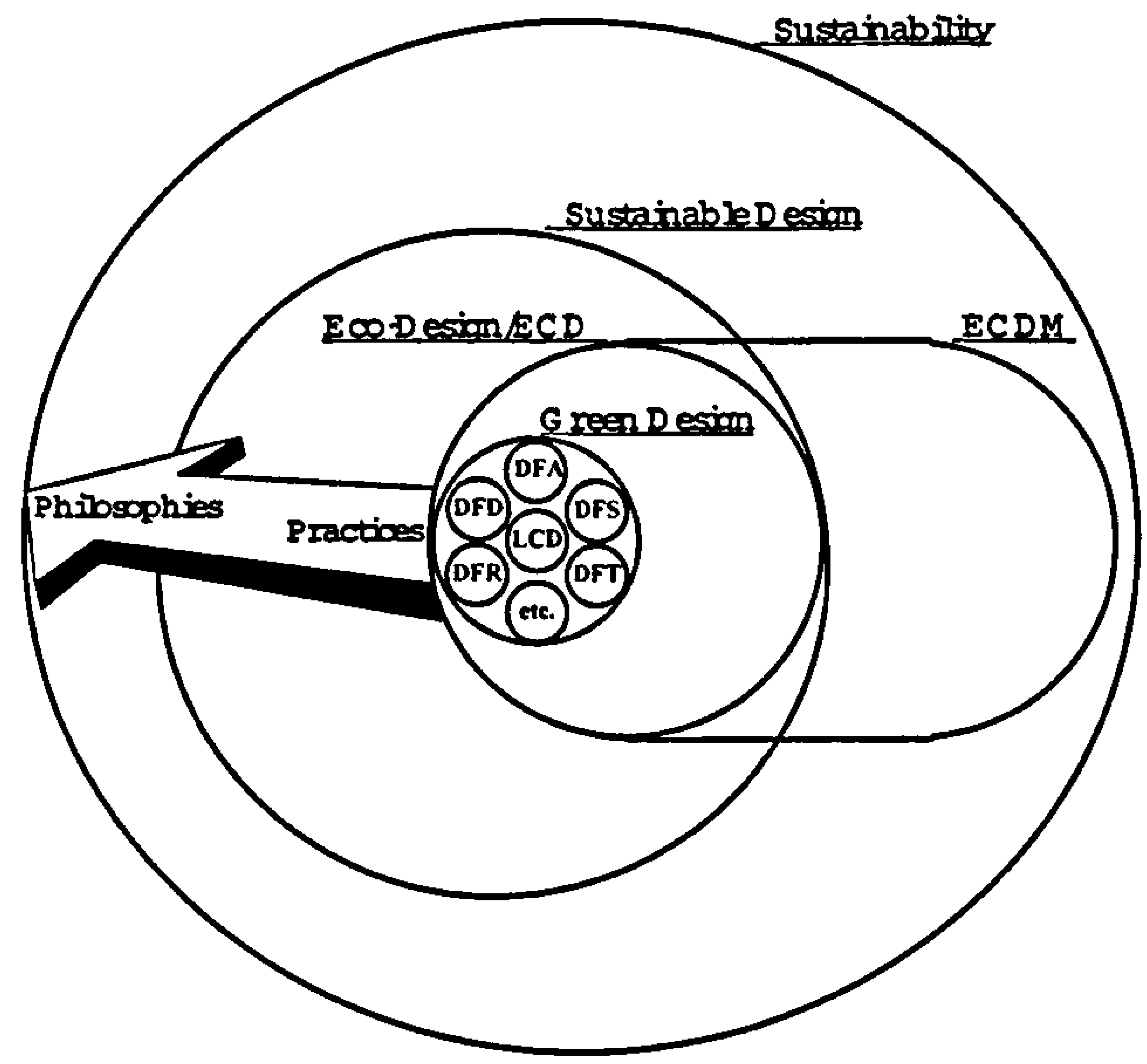

Figure 8 - Relationships between environmental design practices & philosophies [20]

From Figure 8 it can be seen that the further from the centre of the diagram the designer travels, the more philosophical the environmental design practices become, to the point of sustainability, where one can argue that this goal can never be wholly achieved, but must always be aspired to.

To date there is much evidence that the activities at the kernel of Figure 8 are being carried out successfully (as reported by Cairncross [67] and Clegg and Williams [68]), and there are numerous sources of information describing the outer edges of Figure 8. To bridge the gap companies need to formulate an environmental design/manufacture strategy of their own, which is specific to their needs as manufacturers of unique products, yet which relates and reacts sufficiently to the higher demands of policy and to the extremes of global strategy.

If the word 'philosophies' in Figure 8 were replaced by 'strategies', this now gives more understanding to the relationship on a smaller scale between design and design management, and also the way in which companies may develop from single issue environmentally conscious design solutions to more strategic environmental decision-making

2.4.5. Approaching environmentally conscious design

Section 2.3.1 discussed the theory and the practice of product design, and how design considerations should be brought into the design process. Section 2.3.2 went on to discuss the similarities and differences between traditional design considerations and environmental design considerations, in terms of the way in which they can be introduced into the design process. It was highlighted that whilst certain environmental design considerations can be treated in a similar manner to traditional design considerations, some environmental issues require a new way of integrating them into the design process, due to the depth and breadth of knowledge that is required to tackle each issue.

Although industry has a large presence in environmentally conscious design literature (through the conference and journal circuits), most of their literature reports on the tools and techniques of environmentally conscious design - little evidence exists that describes how these companies have approached the integration of environmental considerations into their designs. Lenox and Ehrenfeld [69] go some way to describing a company structure for environmentally conscious design and suggest that for environmentally conscious design to be successful a catalyst is required for information flow between the corporate and business units. If no catalyst is evident, the communication and enthusiasm for environmentally conscious design will not be sustained. Dewberry [70] provides a comprehensive view of environmentally conscious design awareness and attitudes in the UK design profession, comparing design consultancies and design-based industry. Kennedy [71] lays out ten management tools for CEO's to achieve environmental excellence in their business, ranging from the achievement of top management commitment; to creating enthusiasm within the organisation; to seeing detailed environmental improvements as total quality improvements. Other than these examples, there is no evidence of a systematic approach to integrating environmental considerations into the design process.

2.4.6. Reflection

There are many terms connected with environmentally conscious design. Efforts have been made to discuss these terms and to find a relationship between each term. To date industry has largely focused on single issue environmental improvements and is slowly developing knowledge and experience in specialised areas of environmentally conscious design. Academia has concentrated on the philosophical and longer-term strategic issues relating to environmentally conscious design and has begun to look to the implications of working towards sustainability.

In their approach to environmentally conscious design companies often use a catalyst to communicate environmental issues between the design team and management. The attitude of the company towards environmentally conscious design is said to be dependent on the enthusiasm of this catalyst.

There are a number of areas emerging of environmentally conscious design practices and strategies. Some form of catalyst should exist in companies to ensure that environmentally conscious design issues are mediated between the practical and the strategic decision-makers.

2.5. The environment as an opportunity

The word 'environment' has long meant conformance to rule to many people - the need to clean up your act before the world goes wrong, or (more cynically) before you get prosecuted [72]. Improving environmental performance of products, however, need not be a sheer necessity to keep the legislators from the door; many companies have started to see the environment as an opportunity. As mentioned earlier, the European and Japanese car industries managed to gain competitive edge over the US car industry, due, in part, to the fact that they acted fast to new fuel efficiency standards [34]. But the advantage to industry through environmental improvement need not stop at conforming to demands faster than the competitor. Some companies are placing environmental improvements at the centre of their costcutting and marketing strategy, as described by Bonifant et al [73]. Thinking more strategically, Eagan et al [74] propose a system, adopted from a marketing technique, which allows design managers to consider their product in terms of its business importance and its environmental cost/risk. Figure 9 illustrates this tool.

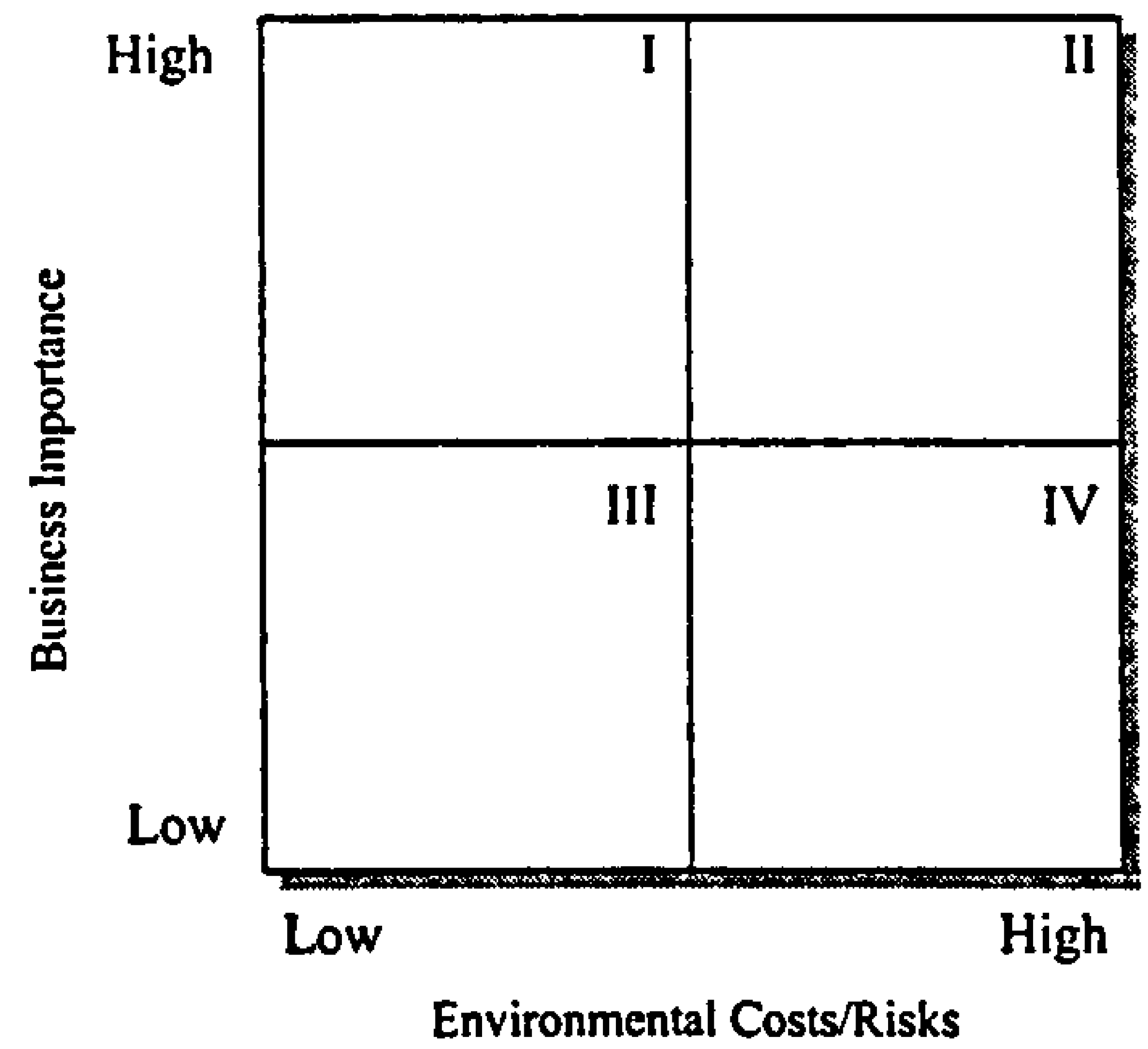

Figure 9 - Environmental management tool proposed by Eagan et al [74]

The authors describe the four quadrants of Figure 9 as follows:

"The best case scenario is to have a product in quadrant I, i.e. high importance, low environmental costs/risks. Items falling into quadrants II, III and IV suggest management attention. Items falling into quadrant IV, i.e. low importance and high environmental risk, should get immediate attention followed by quadrants II and III. Products or processes that fall into quadrant IV may even be ripe for elimination."

Cairncross [67] cites a number of companies who have managed to make a competitive advantage out of improving the environmental profile of their designs, by not only conforming to, but going way beyond legislatory requirements.

2.5.1. Reflection

The word 'environment' can mean positive prospects for a company. By drawing parallels with existing philosophies such as total quality and marketing it is possible to treat environmental improvements as another means to improving the efficiency and competitiveness of the company. Prioritisation techniques also help to consider environmental improvements in terms of their business importance and the company's ability to carry them out.

Proactive companies manage to prioritise environmental changes to their product designs.

2.6. Applied environmentally conscious design research

It is emerging that world-wide, industry has begun to address the many issues related to environmentally conscious design, and there are now pockets of expertise in both industry and academia. Two recent surveys report on the level of research into environmentally conscious design and the amount of collaboration that is present between industry and academia. These are:

- "Environmentally Conscious Design: Matching Industry Requirements With Academic Research", by Argument et al [75]; and
- "Identification Of The Research Agenda And Issues In Relation To Clean Design (Eco Design)", by the Centre For Sustainable Design (CFSD) [76].

The main findings of these reports are as follows:

Academia
"There is a need for increased numbers of researchers in the field of environmentally conscious design in order to broaden the spectrum of research undertaken so that these narrow areas become more relevant when examined as a part of the whole, bigger picture"..."Other academics suggested that, in ten years from now, research will focus on deriving satisfactory general and specific information that can be accessed by industry and academia. The collective opinion suggested that academic research will be more crystallised in the future and will adopt a more holistic approach to environmental design as opposed to the piecemeal approach it has at present." (Argument et al [75])

Environmentally Conscious Design research *"is likely to grow considerably in importance as regulations increase, (especially on waste), market pressures grow (especially as major corporate customers adopt the new environmental standards and place requirements on their suppliers), and as the sustainability imperative increases (requiring large increases in materials and energy efficiency)."* (CFSD [76])

Industry
"The greatest industrial needs were highlighted as: general environmental information; materials information; guidelines and manuals; better advertising of academic research; legislation; senior management commitment." (Argument et al [75])

"There are potential benefits for companies (materials and other cost savings, added value, improved competitiveness, market advantage, and new opportunities from innovation), for society (more competitive business, greater materials and energy efficiency) and for the environment." (CFSD [76])

It is interesting to note that although one of the initial motivators for industry to begin to consider the environment during design was stated as being competition, that both of these reports suggested the need and willingness by industry to co-operate with each other and with academia in order to learn environmentally conscious design skills. The Industry Council For Electrical And Electronic Equipment Recycling (ICER) [53] is an example of how the electrical/electronics industry is co-operating in this manner.

Eagan et al [77] provide an example of where industry and academia have collaborated to deliver environmental design expertise into the training programme of an electronics manufacturing organisation. Sweatman et al [78] provide a further example of such collaboration, this time to develop environmental design criteria within a company's environmental management system.

Dewberry [70] presents a study of UK design-based companies and design consultancies (not exclusively electrical/electronics) and their attitudes to eco-design. This in-depth survey of twenty such organisations concludes with a technique with which to assess a company's attitude towards environmental issues, known as an 'environmental footprint'. This study also reports that beyond a brief knowledge of some terminology, most designers were unaware of the issues surrounding eco-design.

2.6.1. Reflection

Niches of environmentally conscious design expertise are emerging in both industry and academia. Joint research between the two bodies is agreed to be a future target. Industry is reported to need more help with the supply of general environmental information; specific materials information; design guidelines and manuals; and in gaining senior management commitment, whereas academics project that their future task will be to take an holistic view of environmentally conscious design, formulating a systematic approach to its implementation. Although there is reported to be a competitive driver behind industry taking up environmental approaches to product design, co-operation has also been observed through industry forums and self help groups.

A systematic approach to environmentally conscious design is required, in order to satisfy industry's specific environmentally conscious design needs. Companies also co-operate to share experiences in carrying out specific environmentally conscious design improvements.

2.7. Summary

This chapter has explored the literature that documents environmentally conscious design. By following the subject through its development over the past two and a half decades, an understanding has been established of the key motivators to the subject and the significant milestones in environmentally conscious design research and practice. The many design principles that surround environmentally conscious design have been explored, citing those parties who have contributed to environmentally conscious design theories. The terminology that has emerged with the development of environmentally conscious design has been identified and placed in the context of product design. It is interesting to note that the majority of the literature that relates specifically to the practice of environmentally conscious design, and towards which this research is focused, has emerged largely during the period that this research has been carried out; very little directly relevant literature existed at the beginning of this research. This emphasises the highly exploratory nature of the research.

The literature review has established the following findings, all of which serve to justify this research:

- the establishment of electrical/electronics waste as a priority waste-stream in Europe is a sign that an increasing amount of environmental legislation concerning this industry sector may arise in the future, if industry does not act itself to reduce its environmental impact;

- there is a growing need for industry to consider the environmental impact of the products it designs and manufactures;
- a life-cycle approach to product design is required that will aid industry in projecting environmental robustness into product designs. Abridged LCA techniques should aid this process of continuous environmental improvement;
- traditional models of design are not sufficient to fully explain the inclusion of environmentally conscious design criteria;
- there are a number of areas emerging of environmentally conscious design practices and strategies. Some form of catalyst should exist in companies to ensure that environmentally conscious design issues are mediated between the practical and the strategic decision-makers;
- proactive companies manage to prioritise environmental changes to their product designs;
- a systematic approach to environmentally conscious design is required, in order to satisfy industry's specific environmentally conscious design needs. Companies also co-operate to share experiences in carrying out environmentally conscious design improvements.

chapter 3
research method

This chapter investigates the possible methods of carrying out the research and chooses the most appropriate plan of action for data collection and analysis. The chapter demonstrates knowledge of the various approaches to a research question and explains the path taken by the author. Environmentally conscious design is a new subject, and as such has little documented about the methods used to carry it out. A research approach is described that seeks to explore this new subject by observation, to translate the initial findings into hypotheses, test these hypotheses in industry at large and then analyse the results.

3.1. Survey sample: the electrical/electronics industry

The electrical/electronics industry has been a growing sector in the western world over the past twenty years. As mentioned in Chapter 1, retail sales of electrical/electronics goods through large businesses in the UK grew by some 23% in the period between 1990 and 1996; the comparable increase through household goods retailers was 49% [1]. With the increased sales of such goods comes an increase in disposal - either immediately due to the replacement of old electrical/electronic goods or in the following years, as these goods reach their end-of-life. For this reason, and that of increased energy consumption, the electrical/electronics industry sector has been highlighted as an area of great environmental concern world-wide. An example of this concern can be found in the European Union, where electrical & electronic waste has been classified as a priority waste-stream [6]. The industry has responded to this concern by beginning to consider the environment in the design of its products, with the introduction of considerations such as low energy features, recyclability, recycling processes, and environmental management systems.

Given the immaturity of this subject many large firms have made their own efforts to integrate environmental features into their product designs. This has led to an innovative, yet unsystematic approach to integrating environmental issues into design; where one company may have made great progress in improving the recyclability of one of their products, another may have managed to reduce the energy consumption of theirs by half. Progressive companies have even produced best practice guidelines on how to make these improvements to specific design features. To date however, little exists about industry-wide experience in integrating the environment into design, and smaller organisations fall by the wayside, having less capital to commit to environmental design research. It was assumed for this research that the term 'environmentally conscious design' was understood to be the same in each company (this was verified by the author at the start of any conversation); and that common issues were considered to be important during environmentally conscious design.

3.2. Research methods: the options

At the beginning of the research project the research area was established and time was spent gathering the literature that documents the subject. Having absorbed the literature and identified the research need, research ideas were developed. Further work was then carried out to form these ideas into a research question. The research question for this thesis is:

> To discover what is presently happening in the electrical/electronics industry in terms of the successes and problems experienced when implementing environmental considerations into the design process.

The next stage was to consider the future strategy for the research.

When approaching a research question it is important to first understand the way in which it may be explored. The world of social science has provided many classifications and definitions of research method [79,80,81]. Robson [79] describes the initial phase of choosing a research strategy as being able to identify the purpose of the research, which can be classified in one of three ways: exploratory; descriptive; or explanatory. Deciding a purpose should enable the researcher to develop research strategy. Figure 10 displays possible approaches to research, classifying these into five broad areas. These areas are discussed further in the subsequent sections.

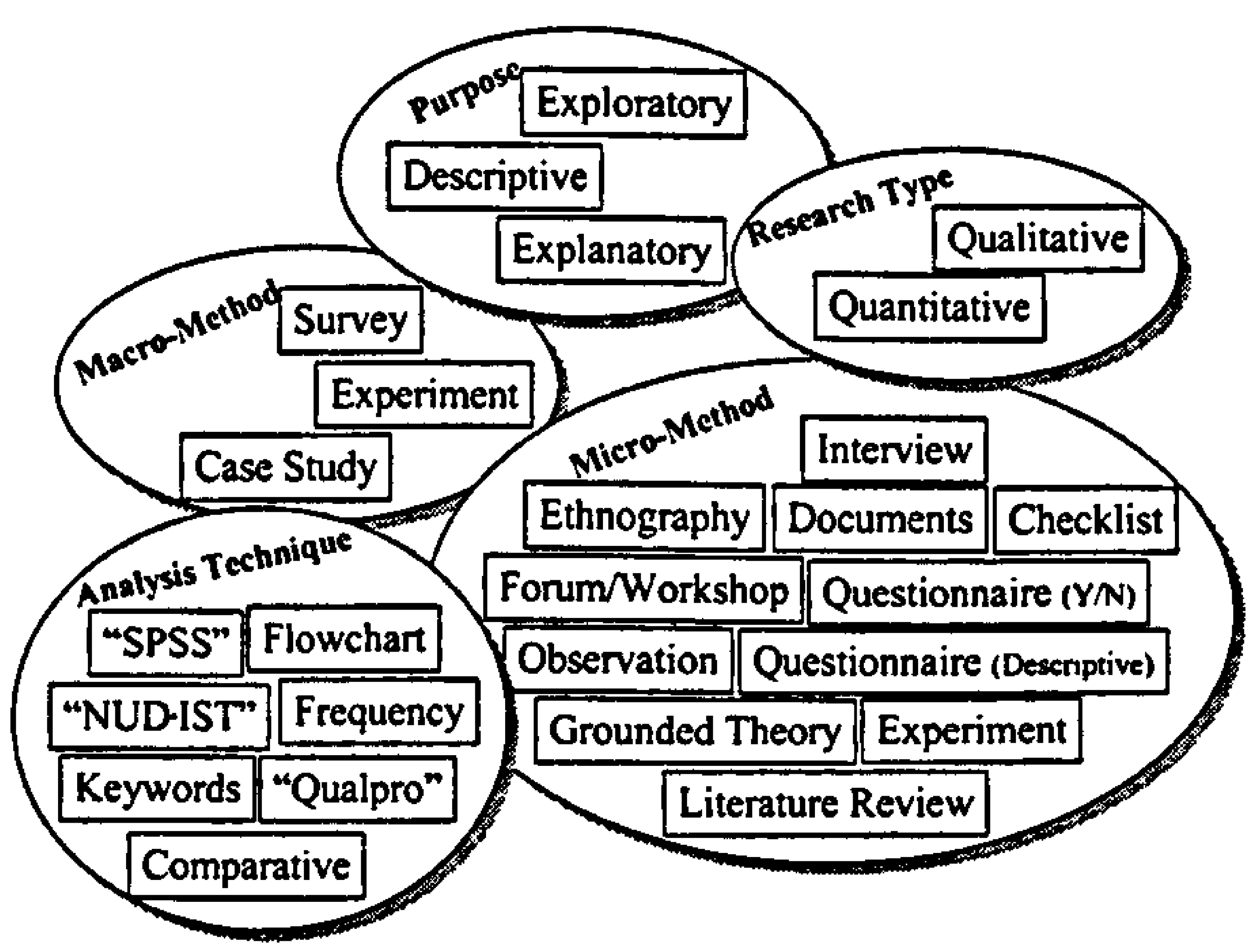

Figure 10 - Research approaches, techniques & tools

3.2.1. Research purpose

When setting out to explore a research question the researcher should first decide the purpose of their work. Robson [79] describes three purposes for carrying out research:

Exploratory research aims to find out what is happening, seeks new insights and asks questions of new and emerging subjects. Exploratory research is generally concerned with new subject areas, there is seldom the opportunity to collect quantitative data, and so a qualitative approach is often adopted.
Descriptive research has the purpose of providing a profile of an established situation, and requires substantial knowledge of that situation. This previous knowledge should allow the researcher to select which aspects of the subject to seek information on. The research can be of qualitative or quantitative nature.
Explanatory research takes an established situation and explains it. This situation could for example be a problem, and the research would entail gathering the data (qualitative or quantitative) to explain the reason behind this problem.

The previous chapter concluded by identifying the need for research into the structure of environmentally conscious design integration in the electrical/electronics industry. Many companies are using some techniques to reduce the environmental affects of their products, but there is little evidence of a common entry point to environmental awareness, nor a systematic approach to developing this awareness. For these reasons a descriptive research purpose would not be appropriate; the situation is still emerging and the companies involved in introducing environmental practices into their design processes are still learning the advantages and pitfalls of each approach. For similar reasons, an explanatory research approach would not be suitable. The research purpose of this thesis is not to *explain why* companies do environmentally conscious design, but to *find out what* environmentally conscious design *is*, from the companies who actually do it, and to derive what a systematic approach to this subject would look like. For these reasons it was decided that the approach to adopt for the research be one of an exploratory nature. This research approach would allow the author the freedom to ask questions of practitioners and construct a picture of what is presently happening in industry.

The research was of an exploratory nature.

3.2.2. Research type

Research is divided into two widely recognised types; qualitative and quantitative. There is much debate among social scientists about the distinction between qualitative and quantitative research, the need to keep the two types separate [82,83], and attempts to bring the two together [79,84]. Despite this long-standing debate it is possible to find consensus about definitions of the two. The following definitions are the author's understanding of the two research types, based on the literature mentioned above.

Qualitative research deals mainly with the exploration of issues and the generation of theories within new and emerging subject areas. This 'soft' approach to research deals often with human issues and seeks not to scientifically nor statistically prove a hypothesis, but to develop an understanding in the area. The term 'qualitative data analysis' covers many of the techniques used to analyse case studies and semi-structured interviews, in exploratory research [79]. The data collection and analysis activities are often carried out so that they overlap with each other, allowing the researcher to develop an understanding of the suitability of their enquiry in this new subject. The researcher will often begin with a research question alone, and then allow an initial period of research (a pilot study) to help develop hypotheses.

Quantitative research is classically understood as being the research that requires facts and figures to answer a research question by means of testing hypotheses. The research purpose is usually of descriptive or explanatory nature and the research question will contain verbs such as 'test', 'quantify', or 'measure'. The term 'quantitative data analysis' covers the techniques that are used to analyse experimental or survey methods [79]. Data collection and analysis are mainly kept as two separate activities. The researcher will begin with a research question and set of hypotheses at the very beginning of the research project.

Environmentally conscious design is a new and emerging practice. From the literature no one company has shown evidence of carrying out the same procedures or concentrated on exactly the same life-cycle issues as the next. It would therefore be very difficult to design a quantitative questionnaire or to hypothesise that 'x' companies carryout practice 'y' at time 'z' in their design process, and then test this; the sample size of similar companies would be too small. The aim of the research is to explore what companies are doing by experiencing them in practice and by talking to their employees. The qualitative approach of beginning with a research question, then carrying out a pilot study to generate hypotheses from experience, fits better to this type of research approach. The further work required to test these hypotheses will seek to gather information from employees of electrical/electronics manufacturing companies, and will rely on their experiences and informed opinions.

A qualitative approach was adopted.

3.2.3. Research method

There are many types of research method that can be used to investigate a research question. A research method is a statement of the way in which the researcher intends to collect the data necessary to answer the research question. The research method describes: the type of data; the way in which it is to be collected; and the amount of data to be collected. Robson states [79] that it is neither obligatory, nor necessarily good practice for the researcher to carry out one research method in isolation. Denzin [85] reinforces this assertion by suggesting the use of multiple and different sources, methods, investigators or theories to achieve the triangulation necessary to give the research its credibility - an approach known as the *multi-method approach.* When deciding on a plan of action, a good plan should further sub-divide the high-level plan into smaller tasks. It is for this reason that the author has categorised some of these research methods in Figure 10 into 'macro-methods' and 'micro-methods'. It should be noted that the list of research methods presented in Figure 10 is not exhaustive, it represents merely those research methods which were considered by the author.

3.2.3.1. Macro-method

Yin [80] describes three research strategies which are represented by the author in Figure 10 as 'macro-methods'. These macro-methods are statements about three different ways of collecting and analysing the research data. Robson [79] reports a common understanding among social scientists that a hierarchical relationship exists between these macro-methods and the research purpose:

- *"case studies are appropriate for exploratory work;*
- *surveys are appropriate for descriptive studies; and*
- *experiments are appropriate for explanatory studies,"*

but states that this need not necessarily be the case; other strategies may be used for other research purposes. The following descriptions are the author's interpretations of Yin's [80] and Robson's [79] descriptions of the three macro-methods.

Surveys are the act of collecting information from a defined community of participants. The information sought is of a generally standardised nature and facilitated by means of an interview (be it structured or semi-structured). Surveys accept the fact that a relatively small amount of data is to be collected from a large sample. Surveys are often used for descriptive research purposes, where trends and opinions can be gathered, but also have a place in exploratory research where reasons behind carrying out new practices may be sought.

Experiments are concerned with collecting data to test hypotheses, assess validity of statements and to make general (often statistical) statements about the sample tested. Experiments are often used to explain phenomena in established situations. In situations where the sample is outside of the laboratory (e.g. where the sample is people) the researcher is helped by carrying out 'quasi-experimentation' [86] where the random sample is limited to 'intact groups' (e.g. existing classes in schools) to allow more control over the experiment and thus produce more useful results.

Case Studies concentrate on one particular individual or body of information and attempt to investigate a situation in its own context. Robson describes the case study as, *"a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence"* [79]. Case studies are often used to carry out research of an exploratory nature and allow the researcher the freedom to enrich their findings by means of triangulating the data with multiple sources of evidence. Quite different to surveys, case studies do not choose a large sample, but concentrate on one situation in its own environment; nor do case studies limit their investigation to a standardised, pre-determined line of enquiry; instead they find out as much information as is available, by as many means as are available.

The author approached this new subject of environmentally conscious design in the electrical/electronics industry with knowledge of only the ad-hoc achievements of pro-active companies. On studying the macro-methods above, it was felt that an experimental research method would not be suitable to explore the subject. The amount of pro-active companies attempting environmentally conscious design was quite large, even if their efforts were not formed into a systematic approach for the industry. It would therefore be interesting to carry out an industry survey to collect the experiences of the many companies and construct a methodical picture for the industry. It was felt, however, that at this stage there was too little evidence from the literature about what constitutes a methodical picture of environmentally conscious design, so it would be difficult to produce a representative survey questionnaire. This led the author to continuing the research in two stages:

1. a single case study would be carried out as a pilot to the research, applying the multi-method approach to allow for the freedom of triangulation (this term is explained later in the chapter) to generate a representative set of hypotheses;
2. these hypotheses would be tested by means of an industry survey, asking a standardised set of questions of a wide survey sample - the survey questions having been formed by the rich data obtained from the pilot study.

A case study acted as a pilot to generate the research hypotheses. Hypotheses were tested by means of an industry survey.

3.2.3.2. Micro-method

In this section the single activities that go towards answering a research question are classified as being 'micro-methods'. Described in more detail below, the micro-methods which were considered for this research are listed, along with a brief discussion about their suitability for the thesis.

The **Literature Review** is an important starting point for the researcher to explore the state of the art in the subject area they are planning to research. The literature review should discuss the achievements to date of other research, and bring together work from other disciplines, where necessary, identifying the gap in knowledge which the researcher intends to explore. This is an opportunity for the researcher to demonstrate their knowledge of the subject area. The subjects of 'design' and 'environment' were explored in the literature review, with an emphasis being placed on a histographical view of developing environmental awareness and its affects on electrical/electronic product design.
Experiments, as explained in Section 3.2.3.1, are suited to explain phenomena in established situations. Environmentally conscious design in the electrical/electronics industry is an emerging subject, so experiments would be an inappropriate method for this thesis.
Observation in its practice is described by Robson as, *"You do not ask people about their views, feelings or attitudes; you watch what they do and listen to what they say"* [79]. Observation is seen as being a complement to such research methods as interviews or questionnaires, because of its directness, reporting what people do, rather than what they say they do. This technique was used during the pilot study phase of the research, allowing for the industry survey interview to be formed on the basis of what the author experienced in the organisation.
Ethnography, often described as 'going native', is a type of observation which involves the study of a situation (e.g. a department in a company) by spending extended periods of time immersed in it. The term 'going native' refers to the fact that the ethnographer assumes a role in the situation that allows them to become 'one of them'. The idea behind this is to allow the people within the situation to become comfortable with the researcher and to forget that they are being analysed, so to provide a more realistic source of research data. This type of research method is very involved and can take a long time for the researcher to carry out. One criticism

of ethnographic research is that the researcher will themself be absorbed into the culture of the situation and so colour the output of their work, as they will no longer be able to be impartial about the data they have collected. Environmentally conscious design is a new discipline and for this reason, many companies have not yet managed to implement environmentally conscious design in a systematic manner. This thesis is concerned with exploring industry-wide experiences and drawing conclusions, from interviews, about a systematic approach to environmentally conscious design. An ethnographic approach was therefore felt unsuitable for this research; it could not be assumed at the beginning of the project that any one company would have sufficient environmental practices to observe in such a manner, and ethnography is not suited to carrying out survey-related research.

Documents are an important source of research data and their analysis can be argued to be a feasible method for carrying out a case study. Yin [80] points to this fact when he states that case studies (depending on subject) need not depend solely on participant observation or ethnographic research, but on other sources of information. Documents provided a valuable source of historical information in the pilot study, allowing a picture to be built of design decisions, interactions between design team members and the timing of decisions.

Forums/Workshops, sometimes described as 'focus groups' are a method of discussing issues around a specific topic, with a specialised group of participants. The author founded a forum for researchers concerned with environmentally conscious design, which acted as a regular source of discussion and insight into aspects of certain hypotheses and to strengthen the understanding of issues which supported the research question. The forum consisted of over 50 European researchers, drawn largely from academia. The group took the name eco2-irn[2] and met quarterly, with ongoing discussion available via an internet discussion list. These focus groups formed a familiar, yet impartial test-bed for hypotheses and research ideas.

A **Questionnaire** of the **'Yes/No'** type was considered for gathering data from industry, but decided to be insufficient as a sole source of data. 'Yes/No' questionnaires provide good data for quantitative research in established fields of enquiry, but more in-depth information was sought from participants, to provide answers to the 'how many', 'how much', and exploratory 'what' types of question that Yin [80] describes.

A **Descriptive Questionnaire** was decided to be more suited to this exploratory research. Rather than target a large number of companies with a postal questionnaire about their activities however, it was decided to incorporate the questions into the interview structure for the companies visited in the industry survey. This decision was made to allow time for both the pilot study and the industry survey which, it was felt, would combine to give a thorough line of enquiry.

Interviews are a way of gathering data from a relatively large number of people within a defined community, lending themselves well to a survey approach to research. The type of data achieved from interviews is generally of standardised form and is the result of concise questioning. This differs to ethnography or observation in so much as no relationship is built up with the subject of the research; instead straight answers are obtained from straight questions. Structured interviews have the advantage that due to the repeatability of the questioning, many cases can

[2] eco2-irn - ecologically & economically sound design & manufacture - interdisciplinary research network

be explored and compared, whereas open-ended interviews are often suited to case studies, allowing the researcher to ask the subjects for facts and opinions, and so build a deeper understanding of the subject [80]. It was decided that an interview technique would be well suited to this research project, provided that sufficient time was spent formulating deciding the focus of the interview. An interview questionnaire would most reliably be formulated by carrying out a pilot study in a company and also by testing it on focus groups before going to industry at large. All interviews were recorded onto micro-cassette and transcribed, to assist data analysis.
Grounded Theory is described as being a method of *"carrying out qualitative research when generating theory is the researcher's principal aim"* [87]. The idea behind grounded theory is that no hypotheses exist at the beginning of the research to be tested; instead a situation is explored from first principals in order to build the theory and not to test it. Although this method was not used for the primary data analysis, the literature surrounding this research method proved to be a useful guide, especially during the pilot study. The model of environmentally conscious design integration reported in Chapter 6 was developed with the teachings of grounded theory in mind.

> A number of micro-methods were employed in the pilot study.
> An interview technique was adopted for the industry survey.

3.2.4. Analysis technique

There is a host of data analysis techniques that a researcher may choose from to form results from their research. These are represented, only in part, in Figure 10 and range from long-hand methods to computerised methods, from qualitative to quantitative, and are designed to analyse the data that results from case studies, to experiments, to surveys.

As described earlier in this chapter, the research was of a qualitative nature, so some of the analysis techniques could be discounted immediately. From the seven analysis techniques presented in Figure 10 five were considered as being contenders for qualitative data analysis. The five techniques are considered in further detail below.

Flowcharts are a way of following a process from start to finish, encompassing all decisions and eventualities along the way to the finish point being reached. Flowcharts use a simple standard set of symbols to signify actions, milestones and decisions. Evans et al. [88] give specific examples of the use of flowcharts, which tend to follow more formal procedures, where specific decisions have to be made. When collecting data for environmentally conscious design, however, it was uncertain what the specific decisions or actions were, so any flowchart would be extremely complex and not necessarily correspond to the next. Flowcharts are also unsuitable for representing experiences and opinions, which was the main element of the data collection.
QSR NUD•IST[3] is a computerised, object-oriented analysis method, developed at La Trobe University, Australia. It facilitates the coding of qualitative data from

[3] **QSR NUD•IST** - Qualitative Solutions & Research Pty Ltd., Non-numerical Unstructured Data Indexing Searching & Theorising

interviews, videos, books, and any media for manipulation into a series of structured hypotheses. Using this technique research hypotheses may be altered by a simple automatic re-coding process as the understanding of the data develops. One of the main advantages of the software is its ability to group data severally and separately into an unlimited number of sub-categories (known as *nodes*) without disturbing the original format of the text - all documents retain their separate integrity within the NUD•IST library. This allows the user's ability to group similar and causal events to build a bigger picture from a series of small stories. The NUD•IST software falls into the category of 'theory builder' analysis techniques, allowing the researcher to form new theories by means of a sophisticated set of text search functions, based on a coded text system.

Frequency Distributions are primarily a quantitative analysis method; their use was considered to represent patterns of response within the electrical/electronics industry. It was finally decided not to include any frequency distributions due to the prejudices that they might convey to the reader. In the author's view it did not always follow that a 90% frequency response to a particular decision meant that this decision was the best for the environment, nor did a low frequency response mean that that decision was a poor one. The companies interviewed in the industry survey appeared to be at different stages in their implementation of environmentally conscious design. For this reason it was felt that frequency distributions would have little meaning, and certainly no guidance about how to integrate environmentally conscious design into the design process.

The technique of pulling **Keywords** from text and listing the contexts in which they appear, (known as 'keywords in context', or 'KWIC' lists) is one that is often used for literary analysis, as Robson states [79]. The use of KWIC lists was considered to investigate the use of terms such as 'environmental champion' and 'design model', but it was decided that NUD•IST possessed this functionality, to a limited extent, in addition to its other facets, as mentioned above.

QualPro is a computerised qualitative data analysis tool which falls into the category of 'code and retrieve' techniques. It offers comprehensive support of text coding and also has a good search technique inherent. It was decided not to use QualPro due to the lack of manipulation capability for the use of theory building, and also because the author had previous knowledge of NUD•IST.

It was felt that NUD•IST was well suited to serve the research objective of investigating the integration of environmentally conscious design in the electrical/electronics industry and building a model to explain this integration. For this reason and the fact that the author had prior experience of the software, NUD•IST was chosen. More detailed information on NUD•IST can be found in Appendix 1.

Data collected from the industry survey were analysed qualitatively using a software tool entitled 'QSR NUD•IST' where appropriate.

3.3. Approach chosen

Having discussed the various possible approaches to the research, a series of components were chosen, as highlighted in Figure 11. This gives a general idea of the types of research, data collection and analysis techniques that were intended for the thesis, but does not yet give any chronological structure to the research.

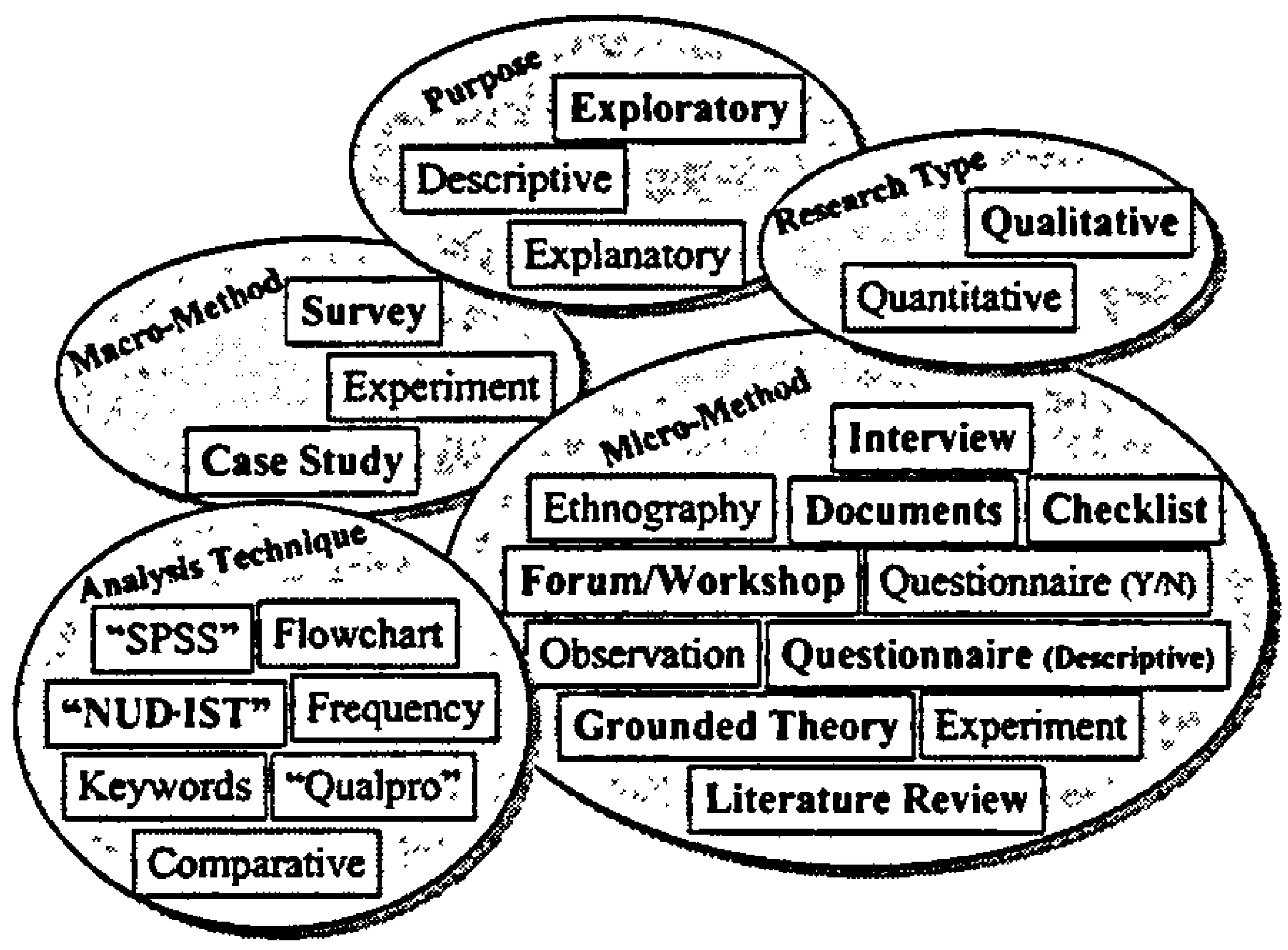

Figure 11 - Chosen components of the research method

Figure 12 shows how the research for this thesis was carried out. The picture is split broadly in to four bands, which represent the four main methodological milestones.

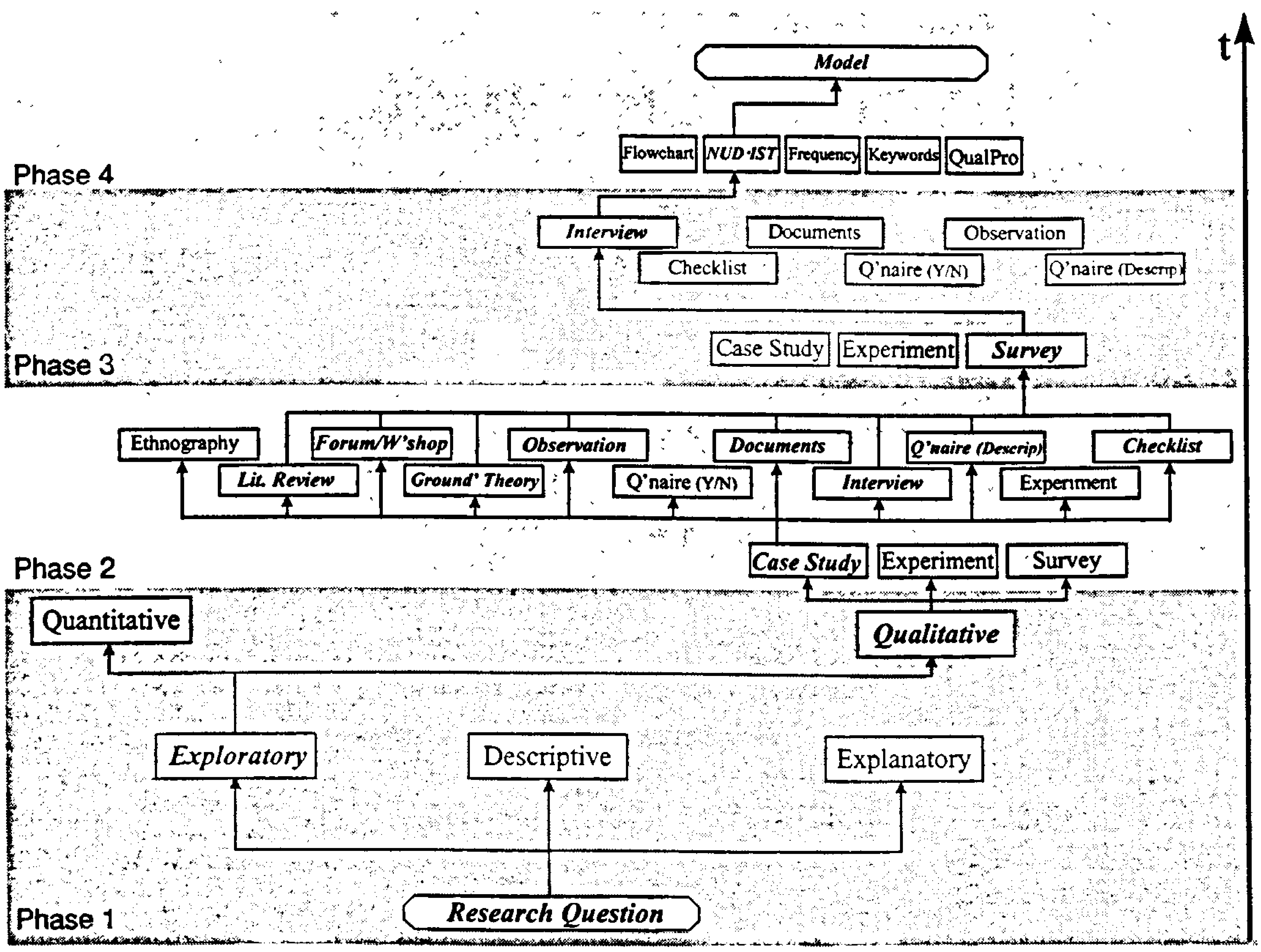

Figure 12 - An emerging research method

Phase 1

After a detailed *literature review* the *research question* was set and it was decided that the work would be of an *exploratory* and *qualitative* nature.

Phase 2

A set of hypotheses were defined as the result of carrying out a *pilot study* in an electrical appliance manufacturing organisation. The pilot study allowed for the *freedom to triangulate* any data by the use of different data collection techniques and to gather in-depth data from a specific case. By their nature case studies allow the researcher to ask tomorrow what they did not get chance to ask today, unlike interviews where all the questioning must be packed into an hour or so. The result of the pilot study was a collection of rich data which could be evaluated and formed into *three hypotheses*.

Phase 3

A choice was made to pursue these hypotheses by means of an *sector-wide survey*; *interviewing* was chosen to be the most suitable technique to employ for data collection. A sample of seventeen electrical/electronics companies from the UK, central Europe and the USA was identified. This wide sample was possible due to the research and funding provisions of a closely related project funded by the EPSRC[4], entitled *DEEDS*[5]. Twenty four people were interviewed from this sample. The interviews were semi-structured in nature and lasted an average of 1½ hours. The interviewees' job descriptions spread across design management, environmental management and engineering design, as shown in Table 7 in Chapter 5.

Phase 4

This phase of the research entailed the *data analysis* and *model building*. Data from the twenty four interviews were collected and analysed using *QSR NUD•IST* and the three research *hypotheses were tested*. The data analysis technique employed allowed further insight into the actions of companies, meaning that a model could be built to describe the way that the electrical/electronics industry was integrating environmental considerations into design. This model provided a framework for *discussion about recommendations* for a systematic approach to environmentally conscious design integration, providing guidance about whether a company's environmental decisions were placed within the areas of most reputed success.

Figure 12 is broken down into its phases and used in the next three chapters of this thesis to remind of the research method for each chapter.

3.4. Benefits and weaknesses of the research approach

Carrying out a pilot study meant that a narrow, but deep view could be taken of one company at the beginning of the research. This gave the opportunity to take time to explore any curiosities and research issues, and to gather rich data from a specific source. This ensured that the research hypotheses were strengthened and relevant, due to the fact that they were built upon an actual data from industry as well as existing literature. The progression from the pilot study to the industry survey allowed for the hypotheses to be tested among a wide audience from industry. Experiences from the pilot study would aid the structuring of the interview questionnaire, to ensure more reliable questioning. The advantage of carrying out a sector-wide survey was that the hypotheses were tested in a number of companies representing the design and manufacture of a range of products.

The main danger of this research approach was that the pilot company may not have been a suitable initial test-bed upon which to build research hypotheses. However,

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[4] **EPSRC - Engineering & Physical Sciences Research Council**

[5] **DEEDS - DEsign for the Environment Decision Support**

there is always an element of risk in company selection for research. In this case the suitability of the pilot company was checked for, to a large extent, by looking at their background in environmental issues (through company reports and mission statements), their affiliation to environmental design groups, and their presence in the conference circuit. Another possible danger of the research method chosen was that the unfocused selection of data collection techniques in the pilot study could result in confusing results. However, Denzin's multi-method approach [85] advocates the use of multiple data collection techniques to achieve triangulation. This use of many data collection techniques also gave the author a chance to try many and become comfortable with one data collection technique that was to be used for the industry survey.

One final benefit of the research approach is that it was chosen to be qualitative. This gave an opportunity for opinions and feelings to be taken into consideration in the data analysis, making the final outcome of the research an experiential picture of the electrical/electronics industry's integration of environmental issues into design.

3.5. A note on triangulation

triangulation *n. a method of surveying in which an area is divided into triangles, one side (the base line) and all angles of which are measured and the lengths of the other lines calculated trigonometrically.* (Source: Collins Concise Dictionary)

Triangulation, an originally geographical term, is a method of validating data by means of employing different data collection techniques, different sources or different theories [85] to attempt to arrive at the same result.

Triangulation during pilot study

Triangulation was important during the pilot study in the electrical appliance manufacturing organisation, because it was here where the hypotheses would be formed. Triangulation was maintained by means of:

- finding out what designers and managers did, by observation and document analysis;
- finding out what they said they did, by semi-structured interview, questionnaire and checklists;
- finding out what these people thought was important, by holding workshops;
- evaluating these findings, next to literature.

Triangulation during industrial data collection

The desired output for the next phase of the research - the sector-wide survey - was a picture of actual environmentally conscious design practices within the electrical/electronics industry. It was therefore important that the participants of the interviews were from a representative spread of those people in the organisation who experienced environmental issues first-hand; gaining access to the environmental public relations person in every company would not make for reliable or representative data. For this reason it was sought to interview more than one person in each company. For their own (time and cost) reasons this was not always possible; sometimes a compromise would mean that a group interview be carried out, where two or three participants were present. The final sample resulted in four design managers, three designers, twelve environmental design champions (definition provided on page 68), and five environment, health and safety (EH&S) personnel. This research was not interested in categorising the responses of defined groups of professionals, but in collecting reliable and representative responses. For this reason, once the participant spread had been satisfied, no further attention was paid to the categories.

3.6. Summary

A review of research methods has been carried out by focusing on the social sciences discipline. The strategy for carrying out a piece of research has been categorised into five main phases: research purpose; research type; macro-research methods; micro-research methods; and analysis techniques (as represented in Figure 10). After thorough exploration of these five phases, the following strategy was decided for the research documented in this thesis:

- the research is to be of exploratory nature;
- the research is to be qualitative;
- a case study will act as a pilot to generate the research hypotheses;
- the hypotheses will be tested by means of an industry survey;
- a number of micro-research methods will be employed in the pilot study, but an interview technique will be adopted for the industry survey;
- the data collected from the industry survey will be analysed qualitatively, using a software tool entitled 'QSR NUD•IST' where appropriate.

A picture (Figure 12) represents the path that the author took in carrying out the research. The final deliverable of this research is a model of environmentally conscious design integration.

chapter 4
pilot study

In this chapter a pilot study is presented that was used to build an understanding of what constitutes environmentally conscious design in one company. The company chosen for the pilot study is representative of the industry sector chosen for the research and also pro-active towards environmentally conscious design, allowing a comprehensive base-line to be set for the main body of the research. The research approach adopted for the pilot study was most appropriate to build an initial understanding of the subject in practice. From the findings of this pilot study a set of hypotheses are formed and presented, which will inform the main data collection for the research.

4.1. Company selection

It was chosen to carry out a pilot study at this stage of the research to enable the analysis of the design process in an electrical/electronics manufacturing organisation. The desired output from the pilot study was an understanding of the overall operation, company strategy and everyday tasks of designers and design teams, especially when attempting to implement environmental considerations into their design process. The key criteria for a pilot study company would therefore be:

- an electrical/electronics design & manufacturing organisation;
- access to designers and design teams;
- an organisation who already have some experience incorporating environmental decisions into design;
- an understanding audience, willing to have various research methods used on them;
- easy access to people, company information and product design information.

It is not common for all of these traits to be found in one company [79] and the researcher often has to state the short-comings of the company as a research medium. Fortunately however, for this case it was possible to obtain access to a proactive company, via a research project on which the author was working. The DEEDS project established links with two organisations who sponsored and supported the project, by allowing access to their design teams and providing real-life projects to work on. (Links were also established with a further thirty companies for lesser involvement in data collection.) One of these companies, who will be known as

'Company A', allowed an extended period for the author to carry out this pilot study. Company A is an electrical domestic appliance manufacturer.

4.2. Research method

The ultimate aim of the pilot study was to form a set of hypotheses, built upon an understanding of how one organisation was managing to incorporate environmental considerations into the design process. As mentioned in Chapter 3 (see white highlighted text units in Figure 13 below), a number of techniques were used to gather the data during the pilot study.

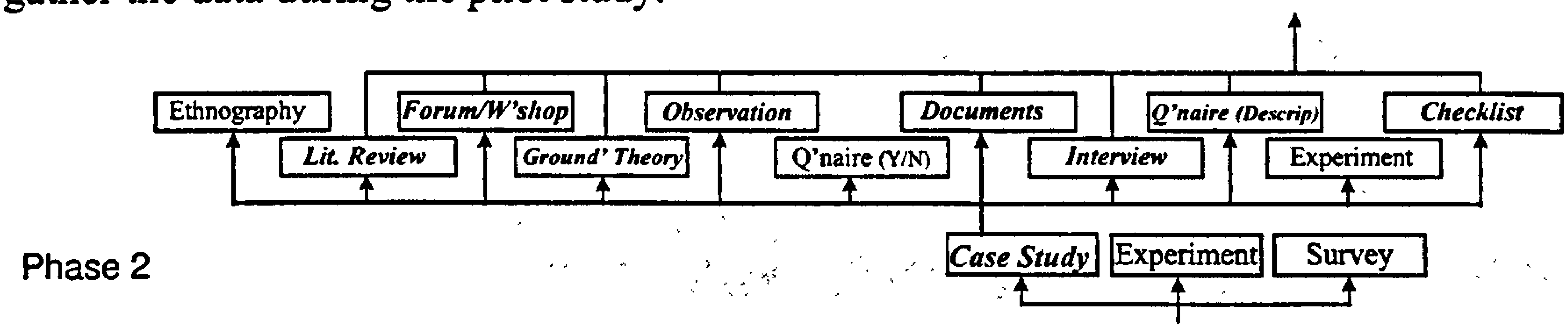


Figure 13 - Research method for pilot study

The advantage of carrying out a pilot study as a means to formulating hypotheses for the research is that the extended time spent with the company allows for observations to be made that would not be possible with most other methods of data collection. The critically small window of opportunity normally available when interviewing a member of an organisation (usually 1-2 hours) can also be avoided, meaning that what the researcher forgets to ask today can be asked tomorrow. The use of many data collection techniques here followed Denzin's multi-method approach [85] to data collection, in order to ensure triangulation of data, and to evaluate different data collection techniques for the primary data collection during the industry survey. The remainder of this chapter reports on a number of observations that were made in Company A over a series of thirty days. These thirty days were completed over the course of three months. The author had daily access to engineering and industrial designers, and limited access to marketing, design management and manufacturing personnel (i.e. meetings had to be arranged with the latter three groups of people).

The research techniques highlighted in Figure 13 above were all used inherently throughout this pilot study.

The *literature review/documents* techniques were used to study previous and present design manuals and all papers and reports that had been written on behalf of Company A, relating to environmentally conscious design.

The *workshop* technique was used as a means to gathering information and opinions collectively from design teams about their experiences with environmentally conscious design. Past design projects were often used in these workshops to focus designers' minds on the question of, "what would we do differently if we were to do this again with the environment in mind?"

Grounded theory was the general approach of the pilot study. The ultimate aim of the pilot study was to generate hypotheses for the primary data collection. The starting point was access to a willing company.

Observation was an important means of collecting data throughout the pilot study. There were extended periods when the author was left to watch the day-to-day occurrences of the designers' jobs. Much of the data recorded in this chapter, and many of the ideas to carry out a line of enquiry with designers were started from being able to sit and observe.

Interviews formed a large part of the data collection for the pilot study. These were all semi-structured interviews and focused on issues were used to back up observations made by the author. The quotes that can be found throughout this chapter are taken from the interviews made during the pilot study.
Descriptive questionnaires were used when access could not be obtained to interview members of Company A.
Checklists were used once in the pilot study (Section 4.4.1.1), to assess the consensus of opinion about the responsibility for product design decisions.

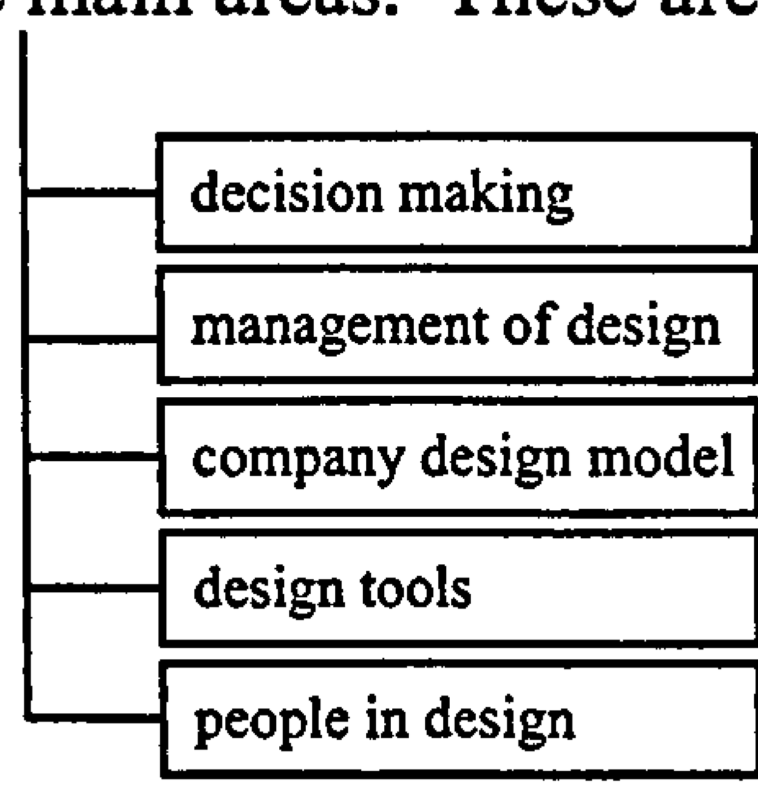
4.3. Understanding the state-of-the-art

The first task in this research was to understand the practice of design in the company. Design observations were based on engineering design theory, as documented in Section 2.3.1. Much of the observation carried out in this pilot study has captured state-of-the-art in Company A; in only a few instances were participants asked to project their views into the future.

4.4. Observation by in-house interview and intervention

On entry into the company the research purpose and expectations were presented to the design team, along with a clear set of requests for co-operation from the employees of the company. The employees were asked to make available their time to talk about their experiences, and to possibly become involved in group discussions. Design management gave permission for access to design documentation so that the history of previous designs could be followed, to gain an understanding of the company's design activities.

There follows a series of observations from Company A that, for ease of reading, have been categorised into five main areas. These areas are:



4.4.1. Decision-making

The decision-making process is core to the design activity. Design decisions are often carefully assigned so that they fit into the correct stage of the product development process. Two main types of decisions were identified during observation:

- strategic decisions, affecting whole product ranges and company strategy; and
- product-specific decisions.

It could be argued that the way to proceed in Company A would have been to concentrate on influencing strategic environmental decisions so that whole product ranges could be altered at once. However, it is was also viewed that focused studies uproot many interesting details, which in turn ask questions of strategy-makers. For the purposes of this pilot study, access was limited to designers and design management meaning that no data could be collected about Company A's strategic product decisions. By focusing on product-specific decisions a narrow but deep view of Company A's practices could be viewed. The next section explores the decisions made within Company A, in terms of who made decisions, the timing of these, and what level of decisions were made at the different stages of the design process.

4.4.1.1. Who makes the decisions?

In this pilot study it was felt important to understand who made which environmental decisions in the company. As a result of informal interviews with product designers four main issues were revealed, relating to who makes key decisions.

a. who makes high-level product design decisions?

For all designs in Company A it was observed that three high-level product decisions were made by the following departments (information supplied by engineering design):

- styling - industrial design
- performance requirements - marketing
- technology development - development department at HQ [89]

Furthermore, *"marketing do not get involved in the design team,* [after having specified performance requirements] *and as such, information only flows one way between marketing and the rest of the team."* [89]

It was evident that the product development process was very much market-led. There did appear to be some confusion about the role of marketing in the very early design stages, between the formalised design process and what actually happened in practice. Often decisions laid out as being those for the consideration of one functional department were already made earlier in the design process, by other departments.

For this reason a questionnaire matrix was used to capture the gap between formalised and actual design within Company A (Figure 14). The matrix was completed firstly by the author to chart where decisions were allocated in Company A's formalised design process.

Design Decisions:
In your opinion, who has a role in each of the topics below?

Decision	production planning	marketing	design manager	project leader	engineering design	industrial deisgn	purchasing	testing	quality
quality targets	××××	×××			×	×	✓		✓××××
new ideas	✓××××	✓×××	✓×	✓×	✓×	✓××			
material types		✓××××	✓		✓×	✓×××	×××		✓
colour		✓××××			✓	✓×××	×		
packaging		✓×××			✓××××	✓××××	×		
styling		×			✓	✓××××			
ergonomics	××				××	✓××××			
final shape		×			✓××	✓×××××			
weight	×××				✓×××	✓×××			
efficiency vs. power	✓×××	✓××			✓×××				
capacity	✓×××	✓×			✓×××				
level of technology	✓××××	✓×××							
filter life	✓×××	✓			×××			×××	××
input & suction	✓	×			✓×××				
power	✓××××	✓××			✓×××				
production requirements			✓×××		✓××××				
tooling			×××	×	✓××××	✓××			
life-time	✓××××	✓××××						✓	✓×
serviceability	✓××				×××	✓××		✓	✓×
recyclability	✓××				✓××××	✓×			✓
environmental decisions	✓×××	✓			✓××××	✓×			✓×

Figure 14 - Matrix used to gather opinions from Company A's designers [90]

The criteria in the left column were chosen by studying the formalised design model and the product design specification (PDS) for a typical product and listing all of the decisions implied by this documentation. The top row of the matrix tabulates the various functional departments within Company A. The aggregate of the opinions from the first round of questionnaires, which took opinions from engineering and industrial designers, is shown in Figure 14. The ✓'s represent the formalised design model (as completed by the author), which provided an 'as agreed' matrix. This shows where the company's documentation stated that design decisions were made. The matrix structure was then used on a selection of engineering and industrial designers. Their opinions of the decisions made during design were collected and again reflected in the matrix by a series of ×'s, representing where designers felt that they and their colleagues had an involvement in the design process. By studying all of the inputs in Figure 14 it was possible to assess the gap between what the company formally laid out and what was actually practised.

This matrix gave a useful insight into the opinions of the participants about who was making the high level product decisions. In Figure 14 the row describing 'filter life', for example, highlights an area of particular disagreement within Company A about a replacement item in their product that needed systematically changing. The company's formalised design model stated that the filter life for this product was in the hands of the 'production planning' and 'marketing' departments. However, when asking designers about this it was found that, in their opinions, the 'production planning', 'engineering design', 'testing' and 'quality' departments were responsible for this decision. This highlights a discrepancy in Company A between the formal and informal design processes, and the possible consequences if a design change to say, filter life were required, which addressed the wrong people in design. This emphasises the importance of identifying the key people in design (and not simply trusting documentation) if changes are to be implemented effectively.

There was widespread agreement about who made decisions such as new ideas; packaging; weight; efficiency and power ratings; capacity; product life-time; and general environmental decisions. Disagreement existed about who made the decisions in the areas of: quality; materials selection; colour; ergonomics; serviceability; and recyclability. Interestingly, all of the areas of disagreement related to issues that designers had problems with, due either to lack of information about the particular decision or to lack of ownership over the decision. (It was found that if designers were earmarked to make a decision, which had already been made for them earlier on in design, this caused low motivation to give the decision any further consideration.)

b. who makes environmental design decisions?

"Issues of recyclability are covered by Denis at present, and efficiency in the product, covered by either Denis or marketing." [89]

"All environmental decisions come from [head office], *we simply carry out the specifications as they arrive."* [89]

Of particular interest to this thesis is finding out who makes environmental decisions. When discussing environmental decisions with designers two key people were cited as being the main contacts for environmental decisions in design - one person whose job it was to oversee quality and environmental issues for the whole of Company A's design function, the other who was an enthusiastic designer. Neither of these people came from an environmental background, but were respected as being the two sources of environmental knowledge within the company. They were also cited as having an enthusiastic approach to their jobs of ensuring that environmental issues received consideration in Company A. Both people saw their job descriptions as a development of a quality management role, and both people represented Company A on external environmental committees and environmental business groups. It was thought to be a great advantage to have environmental commitment from Company A's headquarters as this provided support and authority to their roles.

One comment that came from engineering and industrial designers, however, was that they were not involved enough in environmentally conscious design activities, due to the fact that specific people had already been allocated responsibility for these tasks. This often led to comments about the under-use of Company A's Environmental Design Handbook; each designer is issued with such a handbook, the majority of which are put in the bottom drawer of their desks and rarely referred to.

c. who makes the decisions in a team environment?

For the year running up to this pilot study Company A had been implementing a new 'IPDP' (integrated product development process) system which meant the reform of their existing paper-based checkpoint design model to a computerised integrated model. The new system enabled a view of who was responsible for each decision and to assess the work behind, and reasoning for the decisions being made. The IPDP process advocated the use of multi-disciplinary teams, which could be observed:

"Industrial design, production engineering, purchasing and engineering design teams were brought together to concentrate on the features, ease of use and tooling that goes into making and then using the [product]. *"* ... *"During the concept design proposal stage, much work is carried out across teams and departments"* [89].

The IPDP system was a new addition to the company's design activity and brought clear advantages with it. The new system meant it was easier for designers to have input into the design model, increasing motivation. There were also plans to put the company's Environmental Design Handbook online as a part of the IPDP system.

d. perceptions of roles

Within the same design specification [91] in Company A, each department had a different perception of their role, which enabled a picture to be built of how and why each functional department was involved in the design process. For example:

Industrial design are involved in:

PI (Project Initiation)

- *industrial design input/involvement at the beginning of the project in order to understand the product from the beginning.*

00 (Concept Analysis)

- *bring in product concepts to the project*
- *make prototypes together with engineering design*
- *produce a good overall concept design*
- *a problem here is that Luton are limited in resources = long lead time = new market ideas = redesign; therefore consultancies are brought in at this stage to aid with the design process*

0 (Concept Verification)

- *final shape verified in CAD, including collisions etc.*
- *the product is followed up for feel and functionality*
- *much more detail is covered here in the checkpoint process - working with engineers to implement the detail*

1 (Product Engineering)

- *ensure that specs are met*
- *collect experience on how to make the product functional as well as beautiful.*

Table 5 - Industrial Design's perspective of the design model [89]

The above example highlights the perception of the industrial design department and their role in the whole design process. It shows the perception of their role as being responsible for the overall look and feel of the product and also in ensuring that the concept design is suitable and successful. The engineering design department give their perceptions of their role in the design process later in this chapter (Section 4.4.3).

4.4.1.2. When are decisions made?

It is widely understood (as can be seen in Figure 15) that the 'shadow' cast by the design function is large in comparison to that cast by other functions [13,92]. Whilst it is recognised that it is important to make good decisions early on, will certain environmental decisions need to be left until later, or at least, finalised later in

As soon as a decision had been taken to freeze the design, any other work towards that phase of the product development was stopped. This is a significant point to bear in mind; what if environmental considerations had not yet been reached when the design freeze occurred? No safeguards had been set in place to ensure that environmental design decisions were incorporated into the design process, and not simply left until near the end of each gate review period.

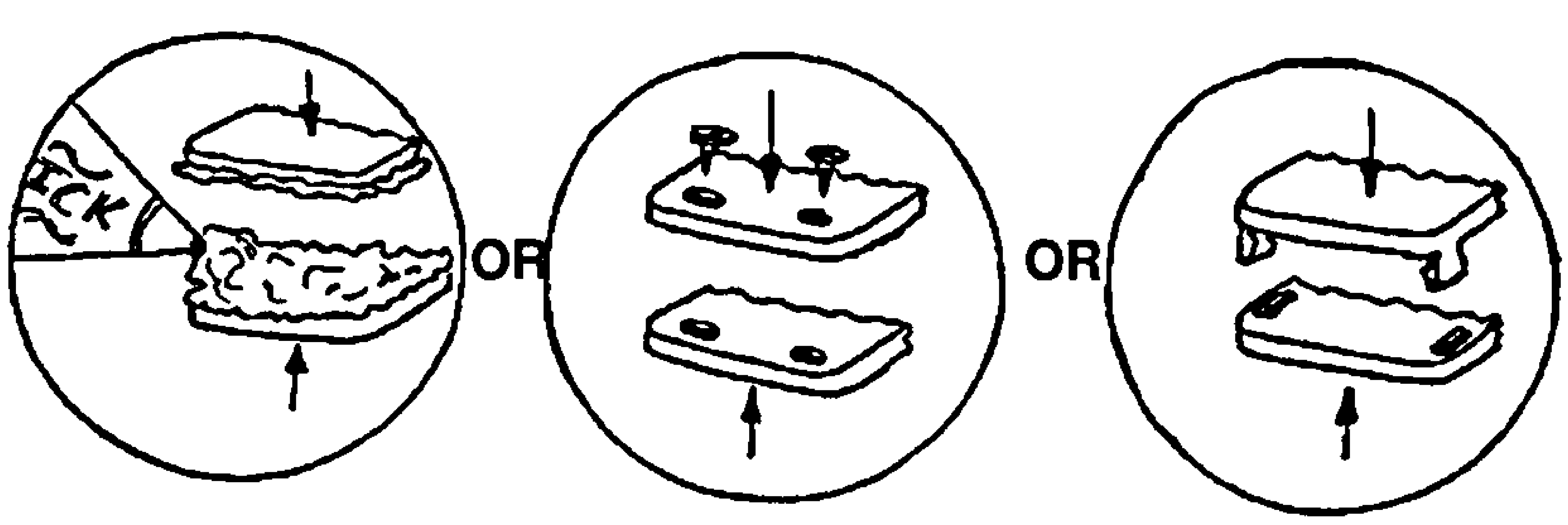
b. assignment and interpretation of design tasks

The product design specification (PDS) is intended to lay out exactly what features a product design should have. In Company A the PDS went a step further to explain what considerations should have been made to bring each feature to realisation [91].

As the PDS was highly respected in Company A and occurred at the very early stages of design, it was a well positioned point for environmental considerations to be applied. Some environmental criteria had been listed at this point, but in little more detail than ensuring the consideration of, say, recycled material.

4.4.1.4. Interdependence of decisions

A decision about DFD may/will affect the DFA of the design. Where else have similar relationships been observed and do they aid or abate the design process? This section reports opinions that resulted from informal interviews and conversations with designers regarding the interdependence of decisions and the questions that environmental considerations raise of other design process.



a. DFA vs. DFD

It was generally accepted that, after a little coaching, DFA and DFD could be reconciled against each other, at no great time penalty to the designer and at no extra cost to the organisation. Designing a product for disassembly does not adversely affect its assemblability. DFD can therefore be carried out without causing any side effects in the product design.

b. power-in vs. performance-out

Company A's product (and in fact domestic appliances in general) have been on an upward spiral over the past few years, in terms of the amount of power they consume. Company A's product only consumed 500W ten years ago. Competition has forced companies to battle against each other in the market-place, where customers buy a product because it is 'bigger and better' than before. This competition has driven companies such as Company A to manufacture products that consume up to 1,300W, almost three times that of ten years ago. This was an obvious environmental concern.

Talking to the product designers it was learned that there is actually a point where the higher input power no longer means that the performance is improved, due to the increased mass of the product and the additional heat being produced. Ideally then, an optimum product power rating is possible, somewhere between 500W and 1,300W. This should be the cut-off point in the design where the input power rating is frozen.

The only problem with the last statement, it transpired, was convincing the marketing department that the product would sell when placed in the shop window next to a competitor's product of double the power consumption.

c. **design life-cycle vs. actual life-cycle**
In the early stages of design (as the PDS was written) decisions were made about the life-span of the product. Depending on how long the product was expected to last, (months, years or decades) different choices of design and materials were made. Hence many cost-sensitive features of the design hung directly on this early strategic choice.

The decision about the design life of a product should reflect directly its actual life in the market-place. One may think that it would be the best option, environmentally, to design a product for a long life-time, using more solid materials in order to increase its robustness during its life. However, if the consumer is actually going to discard the product after just half of this time, the extra investment into a hardier product may also be a waste of resources. This is a difficult thought to reconcile, but needs careful consideration. It is often the case that technology develops faster than the life-span of the product, thus rendering it obsolete.

4.4.2. Management of design

Design Management must decide to whom they will give decision-making authority, how much freedom to give their team within the design activity and how to generally organise the activity. This section explores whether any of these factors had a potential affect on the environmentally conscious design process in Company A, by trying to understand how the design process was organised and how new criteria were introduced into design. Informal interviews were held with design management to gather these data.

a. **project reviews**
"Monthly project councils are held with the whole of the design team and also any other representatives from other departments relative to the project. [Product Team 'X'] *hold fortnightly meetings. Product councils are held quarterly. Divisional directors report on the complete range at* [Company A's] *HQ."* [94]

Project review meetings were the most tangible parts of a designer's month in Company A. These meetings provided a focus after a relatively free period

As soon as a decision had been taken to freeze the design, any other work towards that phase of the product development was stopped. This is a significant point to bear in mind; what if environmental considerations had not yet been reached when the design freeze occurred? No safeguards had been set in place to ensure that environmental design decisions were incorporated into the design process, and not simply left until near the end of each gate review period.

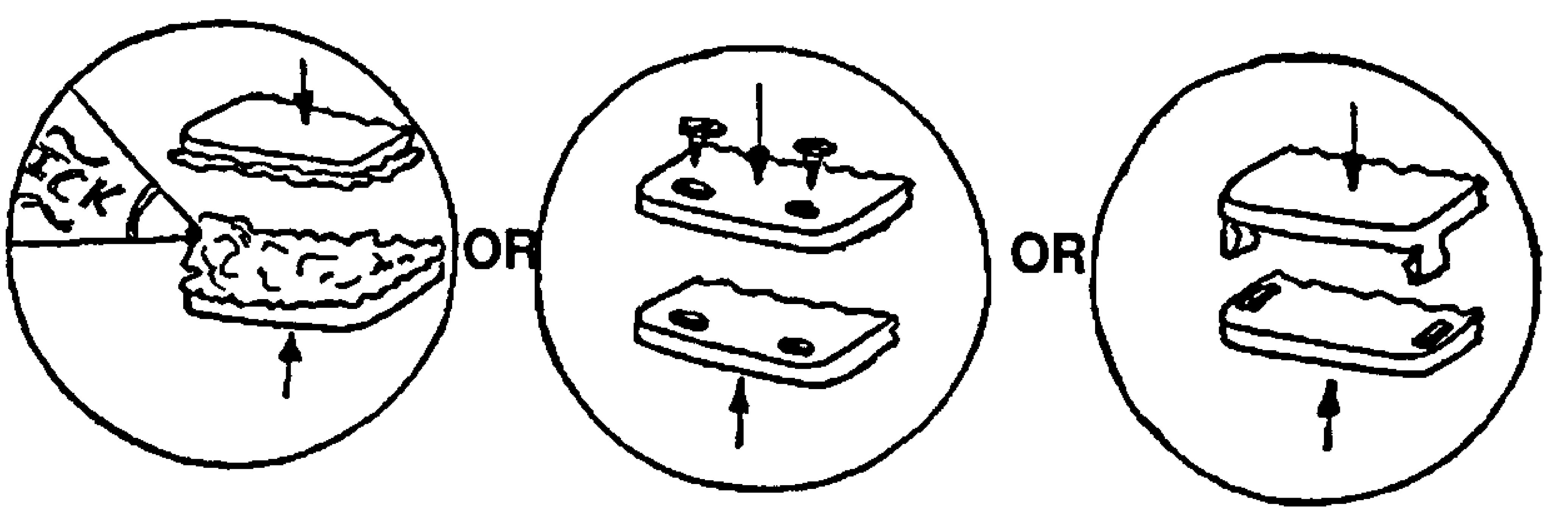
b. assignment and interpretation of design tasks

The product design specification (PDS) is intended to lay out exactly what features a product design should have. In Company A the PDS went a step further to explain what considerations should have been made to bring each feature to realisation [91].

As the PDS was highly respected in Company A and occurred at the very early stages of design, it was a well positioned point for environmental considerations to be applied. Some environmental criteria had been listed at this point, but in little more detail than ensuring the consideration of, say, recycled material.

4.4.1.4. Interdependence of decisions

A decision about DFD may/will affect the DFA of the design. Where else have similar relationships been observed and do they aid or abate the design process? This section reports opinions that resulted from informal interviews and conversations with designers regarding the interdependence of decisions and the questions that environmental considerations raise of other design process.



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Project review meetings were the most tangible parts of a designer's month in Company A. These meetings provided a focus after a relatively free period (organisation-wise) where the designers had been left to their own resources. On attending a project review meeting it was learned that the various tasks from the checkpoint system (such as the ones highlighted in Figure 14) were reported on by the design teams and a status report was given. Environmental issues, such as recyclability and packaging were also discussed with the whole team at these reviews. Problems were discussed within the design team and project target dates were reviewed and adjusted as necessary. The project leader chaired the project reviews and had the authority to reschedule the target dates of the project.

b. IPDP system

"The IPDP [Integrated Product Development Process] *system was developed by* [Company HQ]. *The system is a central process and is computer driven* [Lotus notes and Ami-Pro], *as opposed to the original 'paper' checkpoint system. The system gives full details of project activities as based around the computer; i.e. the computer has all details inherent."* [89]

Each designer in Company A had access to a PC with the IPDP system resident. Their tasks towards each checkpoint stage in the design process were documented on the computer, along with their roles & responsibilities and a detailed description of what was expected in each design stage. The IPDP model leant itself well to being altered, (by those with the appropriate access) which meant that designers felt that they were making informed contributions to the design process. The organisation's quality manual was being implemented into the IPDP system when this pilot study was being carried out, meaning that everyone would be able to easily access the manual to identify their roles towards the company's quality standards, without the need to search through the paper library. The two people who concerned themselves on a daily basis with environmental design considerations discussed making the company's existing Environmental Design Handbook available on the new computer-based IPDP system, so that it may be used more frequently. From the positive acceptance of the computer-based IPDP system, there was clearly felt to be an opportunity to further integrate environmental considerations and advice into the design process, which would be one way to encourage more designers to join in with environmental decision-making.

4.4.2.1. Collocation

This section explores the effects that collocation was felt to have had on the efficiency and effectiveness of design in Company A, and the inclusion of environmental considerations.

a. interaction within the company

"During the concept design proposal stage, much work is carried out across teams and departments. There is, however, much room for improvement with the integration issue." [89]

Interaction between the industrial designers and engineering designers was increasing and the relationship between the two departments was good - the only limiting factor between the departments was now their physical location (industrial designers needed a lot of space, and needed to be close to their workshops to trial design alternatives, whereas engineering designers need to be close to the CAD suite). The informal communication that was taking place within the departments was an undisputed advantage.

b. it's not always possible
Collocation is good where it is achievable and should be taken advantage of, but it must be realised that it is not always possible. For certain product features, design was carried out by third party suppliers, who could be located as near as London, or as far away as Italy.

It must be taken into consideration that any environmentally conscious design tools should be repeatable across different types of design teams. One question is, should a set of environmentally conscious design tools be developed for the 'extended design team' and one for the 'nuclear design team', or should the tools be so generic that they map onto both types of design process?

4.4.3. A company design model

Every manufacturing organisation has some form of design model, be it a checkpoint/gate review process, or an IPDP. Whatever the model, it lays out the company's strategic plan for developing their products. Within this strategic plan each design team will interpret their assigned tasks to suit their way of working. From observing the design teams in Company A and studying their design proceudres it became evident that the formalised design model acted as a guidance for time-keeping, and that within each major mile-post there must be a large element of flexibility to allow for design changes and discussion between different departments. Design models also tended to include actions which are already decided long before the designer received the brief. Were there any alterations to the norm that were so frequent that they should become fixed changes to the design model? If so, how was this done?

a. 'industrial' vs. 'engineering' design model
Comparing Table 5 and Table 6 below, it becomes apparent that each department of Company A took the information from the corporate design model that was directly relevant to their activities.

Engineering design's activity in the design process is as follows:

PI	*Project Initiation*	
	5 year product cycle identified (2-3 year for face-lifts)	
	Product calendar drawn up	
	Market volumes and costs estimated/allocated	
	Product idea	
	Preliminary project proposal	*Engineering Manager*
	Central Product Council	
00	*Business plan - market analysis (customer requirements)*	
	QFD: existing users of [the product]	
	Competition studies - technology; new ideas etc.	
	Technical analysis	
	Packaging specification	
	parts	
	product proposals	

	supplier selection	*Purchasing*
	frequency prognosis	
	FMEA systems	
	project feasibility	
	group project proposal	
0	*Concept verification*	
	Product range specification - tailoring to the market	
	Concept design - more detailed design	
	test plans/ product plans/ ecology analysis/ product specification	
	Project and product specifications	
	Financial analysis	
	Stop/Go decision	
	Product finalisation/Introduction	
1	*Materials Tooling/fixing*	
2	*Design Analysis (DA) run*	
3	*Production Release (PR)*	
	Feedback (6 months later)	

Table 6 - Engineering Design's perspective of Company A's design process [89]

The fact that each department could readily supply information on their roles and responsibilities in each stage of the design process was a good sign that they respected and made use of the design model. As Table 6 shows, the engineering design department perceived their role as providing the technical answers to the product design specification, and broke the product design down into functional units.

b. IPDP advantages

"The advantages of the checkpoint [IPDP] *system are that:*

- *it reduces the amount of faulty* [products] *in the marketplace (ensures right first time); and*
- *it diminishes barriers between the functional departments.*

Most departments seem to be happy with the checkpoint system, with the exception of production engineering." [89]

4.4.3.1. The product life-cycle

As discussed in Section 2.2.2 it is important for designers to understand the concept of a product life-cycles if they are to be expected to work with life-cycle techniques; however there appears to be a mismatch between theoretical and actual perceptions of the product life-cycle. This section captures some conversations that were held with designers about their perceptions of a product life-cycle and whether the company considered the whole life-cycle of their products.

a. perceptions of a life-cycle

Perceptions of a product life-cycle differed depending on whom one talked to. Some people were said to be designing merely to get the product out of the factory gate, whereas others understood the need to consider the ten or so years that the product is in use, and thereafter at end-of-life. The idea of multiple product life-cycles or upgradeability had not yet been thoroughly evaluated at the design stage.

b. learning from life-cycle management in action

In some cases the concept of the whole product life-cycle was being practised. Figure 16 shows a representation of the possible paths for a product during its life-cycle. Also on the figure is an indication of where Company A stood in terms of managing their products.

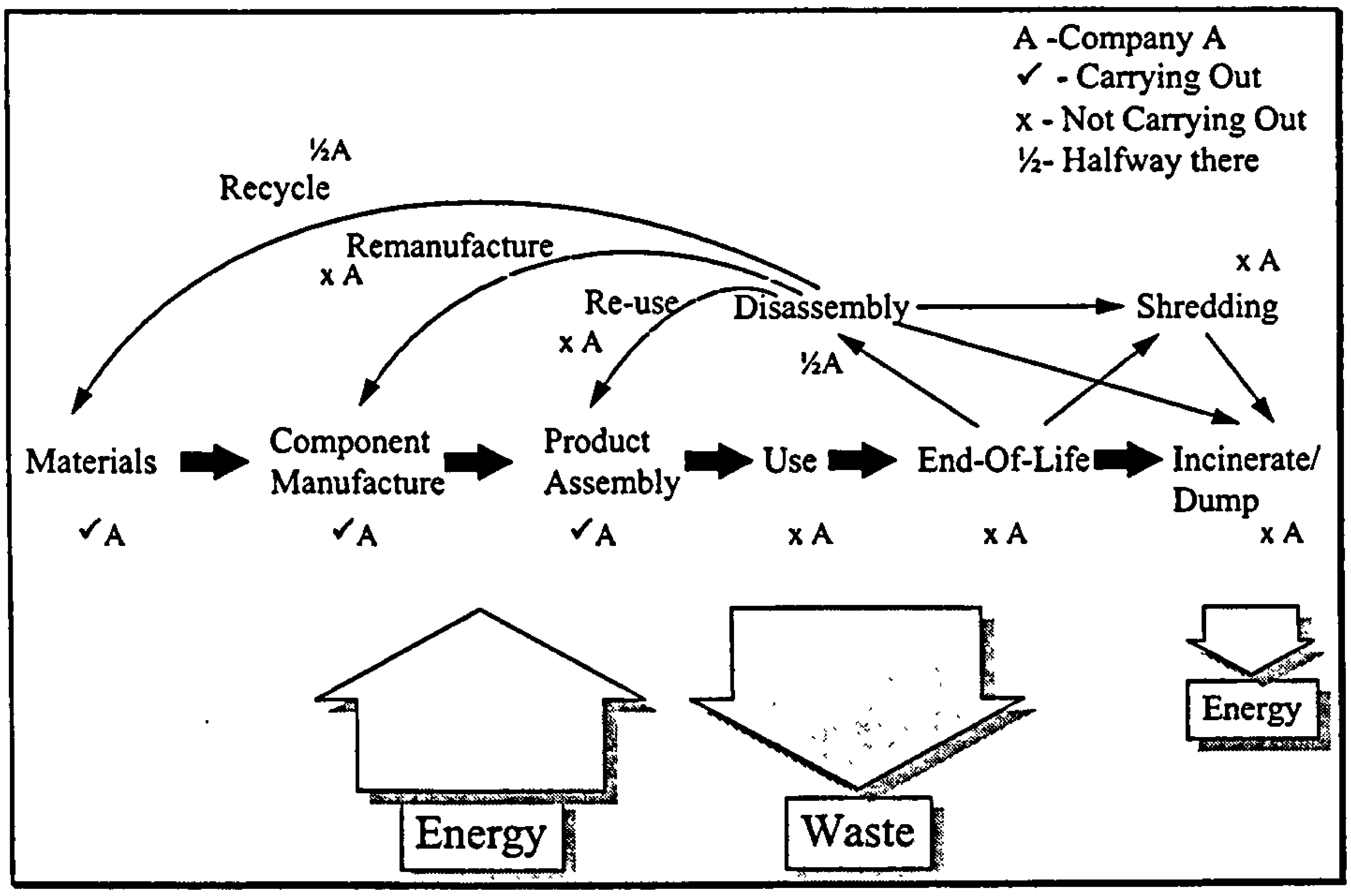

Figure 16 - An 'informed' view of a product life-cycle

Company A had no real relationship with the customer or the product after it was sold. They had a little experience of disassembly (from the design-end only) and a little experience of recycling (in-process scrap) or buying recycled raw material rather than virgin. Other than this their life-cycle activities were limited, as Figure 16 illustrates.

4.4.4. Design tools

There are a number of tools at the disposal of the designer, from QFD to FMEA to DFA/D. Which of these were used/supported in Company A, and would they be of use to the environmentally conscious design process? These data were collected by interviewing the design managers and quality staff pany A.

4.4.4.1. LCA

Life-cycle analysis is described in Chapter 2 as being an objective process used to evaluate the environmental inputs and output of a product, process, or activity throughout its life-cycle [38]. The product life-cycle was not yet understood in Company A, nor was LCA. Some designers admitted to having heard of LCA, but followed this admission with a note of scepticism about the tool. They had heard that it is complex and time consuming, and that results can be bent in any way to suit the individual, depending on where one draws the system boundary.

4.4.4.2. QFD

a. QFD survey

Quality Function Deployment is a process which is used to listen to the voice of the customer and translate the customer's requirements into a product specification that is well targeted to the customer's desires. In Company A,

"this survey was the first of its kind to be carried out. It concentrated on the design of the [product] *and took the following form:*

Ten people of average class-band [class CII] *partook; five people took a* [product from one competitor] *and five people took a* [product from another competitor]. *They had these* [products] *for a one week trial, after which they received* [one of our products] *for a further week. After this two week period they filled in a questionnaire and then partook in a 3/4 hour post-study interview."* [89]

QFD findings
The above survey gave rise to some environmentally related comments:

Product Analysis: Company A's Product is...	
Compatibility	• *bad for materials* • *bad for fasteners*
Progress	• *low choice of disassembly precedence*
Simplicity	• *good in both*
Recyclability	• *good due to low contamination*
Progress	• *improvement on number of fasteners* • *high recyclate revenue: due to low plastic contamination* • *location of screws/fittings etc.* • *paper stickers on products - gives problems* • *minimisation of fittings due to 'blanket' design* • *materials well identified"* [95].

b. repeatability of QFD results
"A very extensive study was carried out for [product X]. *This cannot, however, be carried over and reused in the next project."* [89]

QFD was 'overdone' on the project reported above, which never went to market due to over-design. The QFD exercise had been well implemented in terms of including customers' requirements, but fell down on the elimination of unnecessary features. The result tried to satisfy *all* customers' requirements and so turned out to be unfeasibly complex, heavy and expensive to produce.

Carried out correctly, QFD is a valuable tool, especially as it lends itself to the inclusion of environmental criteria [96]; if Company A's QFD method were remedied and made repeatable, it could be a useful tool for implementing environmental criteria.

4.4.4.3. FMEA

Failure Mode and Effects Analysis (FMEA) was carried out as a 'group away' exercise and was seen to be a natural and very useful part of the design process.

a. the FMEA process in Company A

"For each new product launch, an FMEA meeting is held away from site, over a two day period. No more than six people attend: design engineer; quality control; facilitator; production engineer; tooling engineer; and industrial design.

This meeting takes the form of:

- *identify all functions of each component;*
- *train new team members in FMEA (quality manager does this);*
- *3D CAD prints - specification of FMEA;*
- *exploded views part numbers;*
- *functions listing;*
- *any samples (prototypes: solid model or cast working model);*
- *Design familiarisation (from the models).*

With the various scores that are assigned to different attributes of the product the team is able to assign failure modes to the PC tool in terms of:

severity x detectance x occurrence.

If this function is over 400, then immediate action must be taken." [89]

The group of people who attended this exercise, at the very beginning of the design process (during the 'Product Initiation' stage) were an ideal audience on whom to test out environmental failure modes. This would take some education at first, but should be relatively straightforward to implement into this stage of the design process. The results from the FMEA exercise fed directly into the PDS; this appeared to be a key possibility for including environmental criteria into the early stages of design, (a little closer to the product strategy stage).

4.4.4.4. DFD

a. DFD activity

Design For Disassembly was carried out in Company A as a direct result of a research project completed by Manchester Metropolitan University [56]. All designers interviewed were aware of this work and had attended at least one workshop to learn how to carry out DFD, agreeing that it could tie-in well with their existing DFA practices.

4.4.4.5. Handbooks

The Environmental Design Handbook was not successfully being used. Instead, designers tended to leave the handbook in their bottom drawers, without referring to it.

a. observations of handbook

The following is an excerpt from a set of minutes taken by the author, after a meeting with a collection of engineering and industrial designers.

"It was noted by that the handbook in current format was a good starting point and was well structured, emphasising key issues with an appropriate layout for designers. The key weaknesses of the handbook compared to others available

are the lack of case studies (for example, diagrams of a product that is designed for disassembly) and specific solutions (i.e. if PVC should be avoided what are the alternatives?)
The key handbooks that were presented were the GE Design for Recycling guide and the IVF electronic design guide. These were shown to highlight the use of case studies which could possibly be included to make the handbook more accessible. Examples of systems used to assess a design's environmental impact, such as Eco-Indicator (by Philips), were discussed. Quick approaches for assessment such as those used by AT&T and Motorola were also discussed as possible alternative methods of evaluation. Also noted was that it would be difficult for design to choose different materials based on environmental criteria as these decisions were very limited and made prior to the designers' involvement. It was stated that key strategic methods were also necessary, as well as conceptual and detailed design tools.

Comments made about existing handbook:
- *contains no case studies from other success without or within the company;*
- *gives absolute instructions, but no guidance as to where to go from there (e.g. "must not use PVC" - but no alternatives suggested);*
- *the appendices do not relate exactly to the actual design process - could cause some confusion;*
- *a deeper level of information is required throughout the handbook to supply the designer with essential guidance that s/he does not need to go on a deep exploration for;*
- *another example relates to the materials markings; instead of simply referring the designer to ISO standards, put a level of intermediary information in there, that the company has taken from each standard;*
- *possibility of relating the Environmental Design Handbook to the IPDP system, where each design item in relating to environmental considerations would have a scoring system. The designer would score points for achieving mandatory requirements laid out in the design manual and then further points for the optional/nice-to-have inclusions. There could also be a cut-off score associated here - if an environmental design requirement were to have a minimum score of "5", and the designer could only achieve a score of "3", this requirement would undergo discussion until more points could be scored, and thus more work applied to it;*
- *could also include an environmental checklist - similar to that of Bosch. This should not, however, work in isolation but should be backed up by the handbook to strengthen the thinking behind the decisions to be made in the checklist. Avoid putting questions on the checklist that the designer simply could be expected to answer, because they would simply answer "no" and the checklist would begin to lose its value;*
- *references section: do any of the designers actually have copies of, or even know of these references? A level of information between the guidelines and these references is require;*
- *it was felt that the level of environmental expertise and information held in Company A is quite high - to each question posed about the Environmental Design Handbook, a reasoned answer could be verbally given, but does not translate to the handbook - this does not do justice to the amount of*

knowledge that is held nor the work that has been done by the organisation."

4.4.5. People in design

Individuality in designs comes from individuals with the freedom to implement their creative ideas. No matter what formal structured process is set up, the personal attributes of employees have a significant affect on the success or failure of environmental criteria being integrated into design. Two particular issues were noted in Company A, regarding the motivation of designers and the way in which they communicated to each other.

4.4.5.1. Motivation

If designers think that they are simply carrying out repetitive tasks, rather than designing new products, then they are in the wrong frame of mind to consider new 'constraints'. What factors can/do affect the designer's motivation in everyday work?

a. DFD

Design For Disassembly was carried out in Company A, but the company did not actually take back or disassemble any of their products. This would not be a problem if the designers were told the reason for this disparity in company practice. However, due to the fact that there had been no direct explanation for this, the designers were de-motivated to carrying out DFD.

Company A may have had good reasons for not carrying out any DFD, and may even have had it within the company's strategic plan for the future to begin to take back and recycle their products. Conversely DFD may simply have been carried out to anticipate legislation to this effect. Whatever the reasons, these needed communicating to the designers, so as to maintain their motivation when carrying out the DFD activity.

4.4.5.2. Languages for communicating

Designers are well versed in cost, time and quality. There is no sensible currency yet for environmental performance. How can 'E's be converted into something tangible to the designer?

a. designer's common currency

"It was Martin's feeling that the checkpoint model should have more checkpoints added in terms of cost." [89]

In a market-led organisation the main language is money. Should environmental tools therefore be translated to cost savings, for the designer to be able to easily understand these, or would this diminish the quality of the tools? Perhaps if the designer could see that the use of tools could result in money being saved in each design stage, this would be enough to convince them that they were worth considering?

Some tools presently being developed in academia and industry are using units such as eco-points, to give designers an overall score on a quick environmental analysis. This score can be used to compare to a second design alternative; the lower the number, the better the product is environmentally. These eco-points obviously have no meaning in toxicological terms, but are of great use when used as benchmarks on which to base environmental decisions.

4.5. Reflection on findings from pilot study

The pilot study uncovered various issues that could be adopted and investigated fully in industry at large. Considering the data reported in this chapter, the following section highlights the author's view of some significant issues for environmentally conscious design in Company A.

The success of an environmental design decision was seen to be to be dependent on the position of the person making that decision; a committed corporate attitude to environmental issues; and a team-based approach to environmental decisions. Environmental decisions were felt to be most effective when made early in the design process.

It was important to understand fully who makes the decisions in the design process so that important environmental decisions could be made by the appropriate people, and not ignored under the presumption that someone else may be making them. A correct understanding of who makes which decisions was also felt to be important for planning to include and motivate people when making environmental design decisions. The product design specification was seen to be an ideal opportunity to introduce environmental ideas into the product design process very early on; after this stage, many decisions were found to be out of the hands of the designer.

There were two key people in Company A who were responsible for co-ordinating environmental decisions. One of these people was an appointed quality/environmental co-ordinator, and the other was an engineering designer, who did not have it in their job description to take on such a responsibility, but who had a personal interest in the subject of environmentally conscious design. Neither of these people were educated environmentalists. From this limited view, it seems that enthusiasm and the ability to communicate are more important attributes of an environmental co-ordinator than detailed subject knowledge. This person can be likened to Lenox and Ehrenfeld's [69] environmental catalyst who is said to ensure a flow of environmental information between corporate and business units of the company. Another common term for environmental catalysts such as this is 'environmental champion'. It was found that the skills of finding the correct and fitting sources of environmental expertise to provide to designers can be learned relatively quickly and will develop over time in a manner that will suit the specific needs of the company. A key skill in an environmental champion was found to be the ability to identify and involve the creativity inherent in all product designers towards looking for environmental solutions to product design decisions.

Company A had top management commitment to environmentally conscious design largely via their corporate headquarters. Other factors pointing towards top management commitment in the company included the appointment of an environmental champion; the inclusion of environmental design considerations into the IPDP system (such as the ecology analysis); and the existence of an environmental design handbook. It was felt that without the commitment from top management, certain environmental achievements would not have been possible in the company. The IPDP system ensured that environmental questions were posed to designers at regular intervals in the design process. This is similar to the way in which Olesen [48] sees environmental considerations as being DFX-like inclusions to the design process. However, designers did make comments about not having enough involvement in environmentally conscious design decisions, and that most of the environmental criteria that were listed in their IPDP system were being confined to either the quality/environmental co-ordinator or one very enthusiastic person in the design team. The company's environmental design handbook was also very rarely used, for the reason that there was never the opportunity and time to do so. This could mean that either the environmental champion should have looked to involve more people from design, or that simply providing the system and the framework for environmentally conscious design was not sufficient. Van Hemel and Keldmann discuss [58] this issue and state that there is more to environmentally conscious design than simply providing a framework; the mindset of the designer is fundamental, and designers should be given the opportunity to develop their experiences.

The fact that the company had an IPDP system which was being updated to a computer-based system meant that designers could see more easily who was responsible for each task; and also enabled design management to more easily alter the design process. It was seen as a positive opportunity for environmental criteria to be included into design. It was hoped that the introduction of this new system would alleviate the problem of designers' decisions being pre-empted earlier in the design process. As well as reducing their motivation to be creative, if someone else had already decided, say, which materials to use in a product, some of the environmental issues that designers were supposed to consider about materials selection would not be possible to consider.

Any tools used to incorporate environmental criteria into design should be flexible enough to be used by multi-disciplinary teams and must not consume too much of the designer's time. Designers must have suitable information made available in a reasonable expenditure of their time. Detailed techniques such as LCA are presently too complex and have many limiting factors, as Dewberry and Goggin [40] state. LCA's have often been seen to give inconclusive or ambiguous results which are too complex to interpret. If designers do not feel that the information they get from a tool is suitable or reasonable they use neither the tools nor the information. Another point is that a company may have the best environmental tools and techniques in place, but without the correct application these tools and techniques will remain ineffective. The choice of tools and techniques for environmentally conscious design is key; for example, LCA was felt to be too cumbersome and so not used by Company A. The technique of Abridged LCA (ALCA) could have ensured faster results for the company but had not been attempted.

4.6. Forming hypotheses

The pilot study provided a wealth of information that could have been developed into a number of hypotheses for further investigation, including: the use of specific tools; the training of people; the exploration of corporate strategy. These possible directions for exploration were not thought to be of any less significance to environmentally conscious design, but a choice was made to adopt three hypotheses. The choice of these hypotheses was based on three factors:

- their significance to industry (based on the pilot study);
- their representation in the literature;
- their interest to the author.

The hypotheses that were elected for further research are listed below.

Hypothesis 1

The timing of environmental decisions in design is key to environmentally conscious design; environmental decisions made in the pre-specification stage of design have greater impact on the product.

This hypothesis became apparent in the pilot study. The company was aware that many of the environmental design decisions that were planned into their integrated product development process became useless before the designer managed to consider them, due to the fact that key decisions had already been made earlier on that constrained the product design.

In the literature nothing was found regarding the timing of environmental decisions in the design process. Evidence exists [12,13] to suggest that general design decisions have a greater impact in the early stages of design, so one could imply that environmental design decisions should follow suit, but this has not been documented to date.

The recognition by industry of a need to identify a suitable timing for environmental decisions to be made during design, and the lack of literature supporting this need stimulated the author's interest and led to the decision to investigate this hypothesis further.

Hypothesis 2

Enthusiasm is key to environmentally conscious design; involvement of decision-makers who have the enthusiasm to find solutions to problems is more important than detailed environmental subject knowledge.

Company A had a person who encouraged and drove environmental design decisions in the design teams, and communicated environmental issues across the whole company. This person was not an environmental specialist, but had an enthusiastic approach to their role. This person was said by other company personnel to be key to the sustained consideration of environmental criteria in the design process.

There was evidence in the literature of the need for an information catalyst for environmental design [69]. However, the need for this catalyst to inject enthusiasm and adopt the role of environmental stewardship was not mentioned. Other than this instance, no evidence was found in the literature of the role of environmental champions in environmentally conscious design.

Again the stated value of the environmental champion and corresponding lack of literature made the topic interesting to the author. An attempt was made to find out whether a pattern of this enthusiasm in industry existed and to explore the nature of the role of environmental champion, across electrical/electronics industry sector.

Hypothesis 3

Top management commitment is key to environmentally conscious design; without top management commitment (manifested through the provision of resources; company environmental vision statements; the commitment to achieve recognised environmental standards; the support of environmental training schemes; and corporate membership of external environmental forums) environmentally conscious design does not become an integral part of the design process.

Company A provided examples of top management commitment through their appointment of an environmental champion, the inclusion of environmental considerations into the design process and the membership of external environmental forums. It was stated and observed that without these inclusions of environmental considerations to the design process, there would be no support for environmental improvements in the design process.

The literature provides examples of some form of commitment to environmentally conscious design by describing companies that are practising it, and are creating design tools and techniques for their own use. No literature could be found that explained the role and content of top management commitment in making environmentally conscious design successful. Therefore it was felt to be of interest and use to industry to firstly identify what was meant by the term top management commitment and then to assess the content of top management commitment required for environmentally conscious design to be initiated and sustained in a company.

These hypotheses form the basis of the questioning for the sector-wide survey and are explored in greater detail in Chapter 5.

chapter 5

initial data analysis: hypothesis testing

This chapter describes the way in which the hypotheses were developed into research questions and tested within the electrical/electronics industry sector. The line of enquiry was embodied into a questionnaire which was used in interviews with industrialists. The interview sample is described in terms of the importance of gaining access to key people in the companies; not simply designers, but also design management and people from EH&S. The data collected from industry are presented under the headings of each hypothesis derived in Chapter 4, and the hypotheses are tested.

5.1. Survey sample

The electrical/electronics industry sector has a significant number of examples where research is being carried out to make environmental improvements to the design process, as Section 2.6 details. For this thesis it was felt necessary to collect a range of experience from industry and not simply to follow best practice examples. Although environmental issues are beginning to be treated and progressed on a global level, many local variations to the emerging standards and legislation exist. It was therefore felt to be important to consider the activities of companies in different nations across the world. The budget allocated to the DEEDS project, to which this research was closely linked, allowed for industry surveys to be conducted in the UK, Central Europe and the USA. These three survey regions were felt to be interesting because they would ensure that a wider experience of environmental legislation, standards and market forces, would help to reduce the danger of specific conclusions being reported.

Although it was not possible to carry out a survey of other parts of the world, many of the companies had a global market and so could offer their experiences of operating within the constraints of many other nations. Furthermore, due to the selection of companies with a global market, the survey sample tended towards large multi-national organisations. Small to medium sized enterprises were not targeted for this research for two reasons: the fact that many did not operate within the global marketplace; and the fact that few examples were available (either from literature or personal contact) of environmentally conscious design integration in these companies.

Seventeen companies were visited during this survey, which represented a large proportion of the companies in this industry sector who were known to be active in environmentally conscious design. Fifteen out of the seventeen companies in the survey sample were Original Equipment Manufacturers, the remaining two companies were suppliers to all of the others. The survey sample consisted of twenty four people from seventeen companies. A break-down of the functional spread of these interviewees is presented in Table 7, highlighting a varied information base, which was used to ensure triangulation in the data collection.

Function	Interviewees
design top manager	3
design middle manager	1
design engineer	3
environmental design champion (corporate)	5
environmental design champion (business)	7
environment, health & safety engineer	5
Total interviewees from 17 companies	24

Table 7 - Functional spread of interview candidates

Five sub-sectors of the electrical/electronics industry sector were represented in the survey as presented in Table 8.

Industry sub-sector	Companies
brown goods[6]	2
white goods[7]	2
IT & office equipment[8]	8
telecommunications equipment[9]	3
equipment supplier	2
Total companies	17

Table 8 - Industry sub-sector representation of survey sample

The companies involved in the study were: AT&T, BICC, Black & Decker, Bosch, DELL, Digital, Frigidaire, GPT, Hewlett-Packard, Hotpoint, IBM, M/A-COM, Philips, Motorola, Rank Xerox, Siemens-Nixdorf, Xerox.

5.2. Research method

The pilot study documented in Chapter 4 resulted in the generation of three hypotheses. The intention of the industrial data collection phase of the research was to collect information from the electrical/electronics industry that would challenge the hypotheses. It was decided to collect the data by means of an interview survey - the path followed by the white highlighted text units in Figure 17.

[6] brown goods - leisure use goods such as TV, hi-fi, etc. (this thesis excludes PC's as a brown good)
[7] white goods - domestic appliances such as washing machines, vacuum cleaners, cookers, etc.
[8] IT & office equipment - this thesis includes PC's & peripherals, printers and photocopiers
[9] telecommunications equipment - land-line & mobile telephones, fax machines and repeater stations

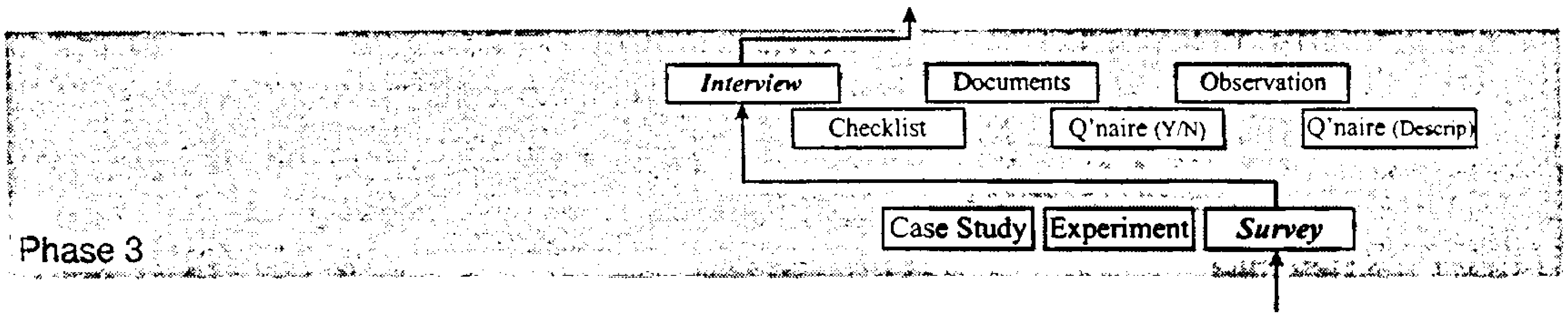

Figure 17 - Research method for industrial data collection

At this stage of the research, many lessons had been learned from the pilot study about the way in which designers were tackling environmentally conscious design, and the information and help they required. The pilot study had also provided the author with the correct vocabulary and context in which to phrase questions in the industry survey. The reason for choosing an interview strategy for this stage of the research was the fact that interviews provide a wider sample group to pose research questions to. (A wide sample was desired to ensure a good representation of opinion and experience in a relatively new field of study.) It was recognised that interviews also give a smaller window of opportunity in which to ask questions; for this reason it was recognised as being important to ensure that the correct questions were asked. The pilot study had provided both a context and a structure for this questioning.

Interviews were conducted in-house in the companies, recorded onto micro-cassette, and later transcribed. To respect the confidentiality of the companies included in the survey, it was agreed that any data used for the research would be made anonymous. Each interviewee had the opportunity to check and approve their interview transcript.

To present each company as an individual case study in this thesis would be extremely cumbersome. The data analysis is therefore split into two parts: the initial data analysis is presented in this chapter, testing each hypothesis; and Chapter 6 is devoted to describing the complex data analysis, where a theory is presented of the way in which the electrical/electronics industry sector integrates environmental decision-making into the design process.

Figure 18 represents the final phase of the emerging research method, where the data analysis technique was chosen.

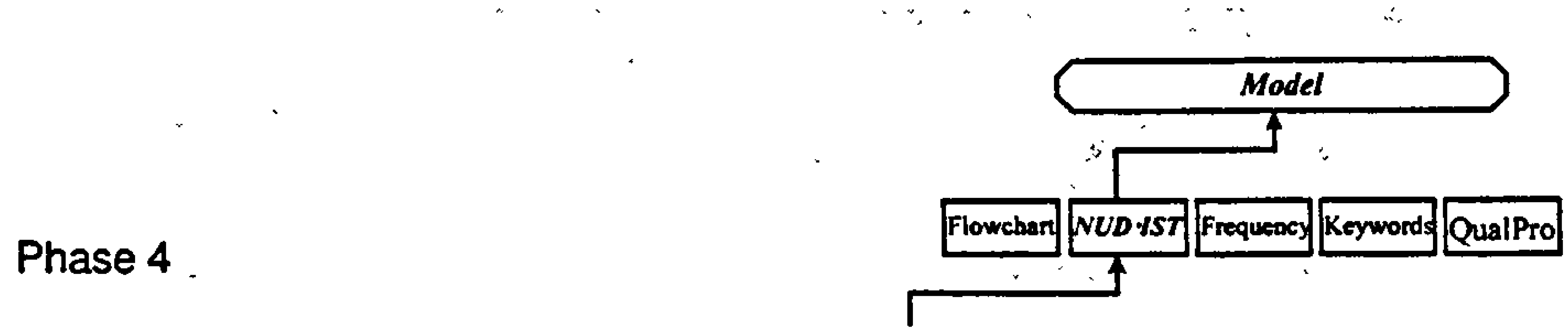

Figure 18 - Research method for data analysis and evaluation

The five alternative techniques reported in Figure 18 that were considered for qualitative data analysis were discussed before choosing NUD•IST. A justification for the use of NUD•IST can be found in Section 3.2.4.

5.3. Interview design and aims

The nature of this qualitative research method was to collect the experiences and opinions of the people involved in the study. There is a trade-off which must be made when collecting data of a qualitative nature - the technique of collecting the data must contain enough structure to ensure that a consistent line of questioning is being applied to each person interviewed, yet it must allow for the freedom of expression of the interviewee. For these reasons it was felt that a structured interview design would be too restrictive (a simple 'question-answer' protocol is suited more to quantitative or factual investigation), while a fully open-ended interview design would run the risk of allowing the subject to wander (time had now been spent formulating hypotheses which were to be tested). A semi-structured interview design was therefore formulated.

The sector-wide survey was also used in the DEEDS project (described in Chapter 4), which made use of the data from these and other companies within the electrical/electronics industry sector. An important feature of the interview design was to be repeatability; the semi-structured interview questionnaire was used by other researchers from the DEEDS project to gather data. Although all data were coded and analysed by the author, interview data from four interviews were used in this thesis that were collected by other researchers, demonstrating the repeatability of the questionnaire design.

To test each of the three hypotheses formulated in Chapter 4 a number of subjects had to be covered. A semi-structured interview questionnaire was designed to ensure that the three hypotheses would be addressed throughout the interviews, without leading the interviewee to a set of expected answers. Five topics were chosen for the semi-structured interview which were felt to be broad enough to allow in-roads to each hypothesis, yet which would ensure relatively reliable types of answer. A lead question was devised for each topic to ensure maintained structure in the interview and a series of sub-issues were noted so that the researcher could prompt the interviewee where necessary. These five interview topics were devised by reflecting on the issues learned during the pilot study, and covered issues that would lead to the hypotheses being addressed. The interview topics and their lead questions are presented in Table 9.

1. **top management commitment to environmentally conscious design** - seeking information on the level of support for environmentally conscious design given by the organisation's management, with regard to the integration of environmental considerations into the design process, and the interviewee's opinions on how important this was. **Lead question:** *"Within your organisation, where does the environmental commitment come from and what role do top management play?"*
2. **design methods used in the organisation** - looking for more detail about the way in which environmental issues were integrated into the everyday design process. If the organisation followed a formal design model, where did the environment fit in, how were environmental issues highlighted and what importance did the interviewee place on the timing of environmental design tools? **Lead question:** *"Does your organisation work to a formalised design model? If so, how are environmental issues integrated into it?"*
3. **team-working in the design process** - looking into the importance of a team environment for environmentally conscious design, the level of leadership required to ensure environmental decisions were made, and the opinion of the interviewee about the inclusion of environmental specialists into the design team. **Lead question:** *"How are environmental issues presented to the design team, and what mechanisms do you use to*

ensure that environmental considerations are made in design?"
4. **environmentally conscious design tools** - evaluating the types of tools and techniques used by designers to ensure the integration of environmentally conscious design considerations into product designs. Whether the tools were in the form of software, handbooks, workshops or checklists, what level of complexity was optimum, and what did designers prefer to have at their disposal? **Lead question:** *"What types of tools to designers have at their disposal when carrying out environmentally conscious design, and what form do they take?"*
5. **problems with environmentally conscious design** - attempting to gain an understanding of what the common pitfalls were for organisations, when designing an environmentally conscious product. This was intended to give the interviewee the opportunity to reflect on their efforts, air any grievances and advise about how they would not perhaps tackle environmentally conscious design if they were to start over again. **Lead question:** *"What have been the biggest problems for your organisation when integrating environmental considerations into your product designs?"*

Table 9 - Semi-structured interview topics and lead questions

Three of the interview topics were design-oriented and two were targeted at both design and change-management issues. This was to gain an understanding of both the act of environmentally conscious design and also the issues experienced when the companies were integrating environmentally conscious design into their traditional design processes. Table 11 relates the research hypotheses to each interview topic.

Interview topic 1 -	hypothesis 3 - top management commitment
Interview topic 2 -	hypothesis 1 - timing of environmental decisions in design
Interview topic 3 -	hypothesis 2 - enthusiasm hypothesis 3 - top management commitment
Interview topic 4 -	hypothesis 1 - timing of environmental decisions in design
Interview topic 5 -	hypothesis 1 - timing of environmental decisions in design hypothesis 2 - enthusiasm hypothesis 3 - top management commitment

Table 10 - The relationship between interview questions and hypotheses

The flexibility offered by a semi-structured interview technique meant that these questions were not always answered in the order presented above, this task being left to the researcher's discretion. All interviewees were issued with an outline of the interview structure prior to their interview. The interview always began with an introduction by both the researcher and the interviewee, to set the context of the interview and to give the interviewee the chance to relax and forget that they were being taped! The interview structure is presented in Appendix 3, and an anonymous transcript is presented in Appendix 4 to illustrate a typical interview.

5.4. Initial data analysis

The remainder of this chapter presents the data collected from the twenty four interview transcripts. As a means of presentation, the data are organised into a series of quotations, grouped under three sections, which correspond to the research hypotheses:

1. timing of environmental decisions in design;
2. awareness and enthusiasm;
3. top management commitment.

It is important to remember that the hypotheses are *qualified* by the data and not *quantified*. It was felt that counting the number of common occurrences of certain practices or opinions would be of little value in such a new area of design practice. This way, if only one person had commented on an achievement that the other twenty three participants had not yet thought of, this achievement would not suffer from a low statistical score. Each quote in the remainder of this chapter is used to test a hypothesis, whether to support or to challenge it.

Due to the need to retain the confidentiality of the companies included in the survey, any quotations to direct product, process or company names have been replaced by a substitution in [square brackets]. All quotations in this chapter and Chapter 6 are taken from the survey's twenty four interviews.

5.4.1. Timing of environmental decisions in design

Hypothesis 1

The timing of environmental decisions in design is key to environmentally conscious design; environmental decisions made in the pre-specification stage of design have greater impact on the product.

This hypothesis argues that environmentally conscious design is dependent on sound scheduling of environmental considerations. It is also argued that the decisions made prior to the product design specification being written are the earliest stage of design in which to alter the environmental profile of a product and also the most important. If this is the case, these decisions need to be supported by sound information and tools.

5.4.1.1. The product design specification

In many of the companies interviewed, environmental considerations were written into the product design specification. The initial motivation for including environmental considerations into design was reported to vary across the survey sample, but the main drivers included legislation, competition and customer demands.

"We have found that some of our sales force have been disadvantaged by not being able to offer a good portfolio of machines that meet the environmental requirements. This results in a reaction that gets elevated and finally our corporate marketing people will realise it is an important requirement, and then it will get to be part of the spec. I don't think we are that clever yet that we are proactive and sort it out before it becomes a problem in every case; the pressure has to be there initially."

"We have recognised the need to have an environmental strategy from a legal point of view so we meet all the legislative requirements. More and more now we are being asked to look at the Eco-labels simply because our sales force are saying, 'We need to have products which are environmentally friendly to have an advantage'. So that is included in our portfolio now and we have a corporate environmental group as well. So I would say it has become increasingly important over the last ten years."

Existing products and products that are already in-manufacture were seen as being the lowest priority areas to target environmental design effort; these were more suited to process clean-up and end-of-life environmental concern. Almost every company recognised the need to consider the environment in the very early stages of design, and particularly in new products, due to the opportunity they gave.

"The first thing that we felt was, it is not really going to be an area where you can make a lot of progress on existing operations without significant investments. So a good place to focus on it is in your new products, and at the design stage."

Although the origins of these considerations were varied, some companies showed evidence of attempting to ensure that they appeared in each design specification across the company. This was achieved by means of formulating a corporate environmental design specification. One company formulated their specification by gathering the key decision-makers in the organisation, running a focus-group to brainstorm ideas and agreeing on company targets.

"In 1990 we took a tuition team out to the Mexican Desert and we actually went out on a Vision Quest about design for the environment. We spent a week out there, and that team came back and kicked off a lot of the design for the environment activities that we have."

The ad-hoc nature in which environmental issues were introduced to designers resulted in fragmented environmental decisions being written into different design specifications across different departments of companies. The companies in the survey that had been practising environmentally conscious design for longer amounts of time and who were operating in the global marketplace saw the need to draw these fragments together to form a corporate specification.

"We are in the process of building a corporate spec. At the moment each division does their own, and I'll show you [our business'] *spec."* ... *"But we are now working on a corporate spec. which will incorporate the stuff from Europe that says, 'quantify certain things', right. It says in there, 'you may be asked to quantify the amount of lead in your product, the amount of copper in your product', and so on."*

Such a specification has a direct affect on suppliers, who will be asked for extremely detailed data on the materials and components they supply the company with. When asked about how this business unit's suppliers reacted to being sent questionnaires which asked for such information, the reply was generally positive.

"All 900 of them that we sent them to complied within a year!" ... *"They were very co-operative. Many cases of industry seem to be sensitised to environmental things, this is in my experience, and when you approach them and say, 'Look we don't want to use these materials', or 'control these materials' or 'we want to make sure that we don't get these into the environment', they don't necessarily have* [our environmental champion's] *experience and expertise in their companies, but they are very receptive to any kind of coaching or direction that we volunteer for them, and we do. I mean, we say, 'Well here is some of the things that you can do, and here are some of the things that you shouldn't do', and they respond to those things."*

"We have very close relationships with our key suppliers of materials and we have a supplier approval process. Part of that is that they must support our ethical principles and they must support our environmental principles. Suppliers and contractors are made aware of our environmental policy and are required to sign that they will support and adhere to it."

As well as being used to ensure the correct supply of materials to the design process, the corporate environmental specification was also said to be useful in gathering customer requirements, in scheduling environmental considerations into the design process and in generating business.

"One of the reasons why [our company] *won the bulk of this work, is that we had a product delivery process that we go through on every single programme, which starts right from technology development to technology transfer; from technology transfer into a concept phase; from a concept phase into a design phase; from a design phase to a demonstration phase; on to production; and then finally end-of-life, or maintenance. So we put together on this programme with the support of the EH&S, a product delivery process for design for the environment, and that starts with pulling together the voice of the customer. We did our bench marking, put together an environmental plan, did an environmental product specification so that we took the attributes that were designed for the environment and naturally cranked it into the product specification where applicable."*

However, not all of the companies interviewed had reached the stage of including environmental considerations into their design specifications, and saw themselves as having a long way to go before they would reach that stage.

"As far as actually setting out to design something that is totally environmentally friendly, we never set out with that goal. Our goal has always been to improve either the performance or the cost."

5.4.1.2. Pre-specification decisions

Having established the business reasons for including environmental considerations in the design process and product design specification, and ensured that both sides of the supply chain were involved in developing the environmental product design specification, there was a focus on the need to look to the stages before the product design specification was written, to ensure that the correct decisions were made up-front. New products were seen as being the ideal opportunity to affect changes to the way in which products were designed with the environment in mind.

"The ideal is coming very early before they have made any decisions at all, and sometimes we manage to do that."

"Rather than test the quality into the product at the end of the manufacturing line, you design it in, and you make all your decisions for the Design For Manufacturability up front. The environmental issues are very similar - rather than making all this huge investment of treating the waste at the end of the pipeline, if you put your effort into the Design For Environmental Quality up-front, then hopefully you can minimise a lot of that waste, and minimise the amount of treatments."

All companies interviewed mentioned that the responsibility for the product design specification included people from marketing, corporate management and design management. Even in a technology-led industry sector, Marketing was the department who drove even the environmental decisions.

"The way in which DFE gets into the design is by the design spec. which we develop in consultation with the marketeers and then that is agreed and signed off and then we use that for the blueprint for design."

"The spec. is the earliest time we see [the environment] *as a requirement but the spec. is only a reflection of the market forces which are now becoming increasingly environmentally conscious."*

Design engineers only saw the product design specification after it was written; they influenced the environmental performance of a product by carrying out the tasks necessary to meet the specification. Some of the people interviewed, however, felt that for detailed issues designers were the best people to ask, and so should have more say in the product design specification stages.

"They typically come in very early in the goals for the project. We set certain goals and that includes energy efficiency, water usage (if it's a wet product), refrigerants, material requirements like CFC's and so forth - it comes in at the very beginning and then the engineers work very hard to meet those targets."

"I think the design community is so key, because that is the community that can help a lot better. When it comes to process changes, product changes, materials changes, that is what the designers are dealing with on a regular basis on new products."

It was universally agreed that the pre-specification phase of design was the most significant in setting the environmental goals and requirements of a product design. Many held the view that if the correct decisions were not made very early on in the design process, it would be most unlikely for any environmental improvements to be made at all, due largely to the cost and time pressures that designers were already under.

"One of the first things we did was to sit down and look at the design process and say 'Where is the best place to influence environmental improvements on the product?'. And it is no great surprise (and everybody that I talk to about this came up with the same conclusion), that you have got to have it in the early stages because once you get down the road and start designing and so forth, and you try to implement something then, then they have to make changes, and then the truth of the matter is, they will never do it."

"We've got to try and get it in very early because if we get past a certain stage there is not a lot we can do to change things."

Furthermore, products that had shorter design lead times meant that there was much more significance on having exactly the right environmental considerations written into the design specification. To support this there was a need to ensure that environmental decisions were timed to occur at key points in the design process.

"The problems vary if you look at the extremes. We probably redesign large systems every three to four years and PC's every six months, so there are different time scales and different abilities to interject to those that are changing very, very rapidly. The actual design phases that they go through happen very rapidly so the ability to interject these things is limited and we have to be very, very quick. That's why it can't stay outside of the design process when it is fast-track, it has got to be streamlined and parallel with their thinking on other things as well. That's the challenge; it's not impossible to do."

"Design guidelines are really the bible I suppose - how we get that into the integrated process design will be the next challenge, the design guidelines and the methodology to check the balances."

5.4.1.3. Post-specification decisions

It seems that not all environmental decisions have to be effected before the product design specification is written. There was said to be a place for decisions to be made about positive environmental changes to products that were in the manufacturing stage. Some of the companies interviewed had an environmental training programme, where they visited design teams in turn (and sometimes even their suppliers) and took a product design that was in progress, assessed it and made recommendations for changes. When asked about how early they tried to affect changes on the products they were environmentally designing, it was revealed that later stages of design could also be positively affected by environmental improvements.

"A design team will call us saying, 'We have a product that is in design and we are getting ready to design it, or we are thinking of a re-design; will you come and give us an assessment of how you think it is doing on environmental responsibility?'" ... *"The ideal is coming very early before they have made any decisions at all, and sometimes we manage to do that. With some products though, that are already in manufacture, we can still make some useful changes, although they are easiest there in product packaging, shipping and installation - things that aren't quite so embedded in the actual design of the product."*

"I should mention that the chassis, the main part of this enclosure, is a buy-out. It is not manufactured [in our company]. *So one thing we attempted to do was to get them to do a returnable packaging scheme because they delivered a high quantity of these things to the* [company] *manufacturing facilities, and then they just emptied the boxes. If they were in expendable packaging they would have had to throw the boxes away so one thing that we wanted to try and do was to reduce the cost and the waste by doing returnable packaging"* ... *"that is one thing that does seem to be able to be implemented after the fact."*

The post-specification stage of design was found to be devoted largely to getting the job done, i.e. integrating the environmental changes into the design process. From a process point of view it was seen to be the job of design management to ensure that the environmental considerations drawn up in the product design specification were carried out, similar now to any other design consideration.

5.4.1.4. A note on multiple product lives

When designing products for multiple lives, the product design specification will look quite different. Many participants recognised the desire to increase the lives of their products, and therefore the robustness of the design. There are dilemmas that occur though, when a product reaches its third incarnation. Those design features that were intended to see the product through many life-cycles may all of a sudden look less attractive, if the product underwent significant changes, due to technology or market forces. In these instances, it was a fear of many that they would be stuck with a long-life design that was no longer suitable. For this reason, many companies kept their focus on improving single life-cycle issues; only a few of the people interviewed had any experience of incorporating design carryover for deliberate product life extension.

"Instead of totally mechanically redesigning that for each product they will put a different processor on it, they will put a bigger disk drive in it, they will put a CD drive, or not a CD drive, they will put more memory in it, there are a lot of different things they can implement on it" ... "So the goodness that we have built into that is going to live on to the extent that if they make these little changes, nothing gets designed out."

"...if you are designing a new product which has a life-time of two or three years... or may be six days, the way things are today (!), you can make a pretty good prediction of what your Corporation is going to be like when that reaches it's end-of-life, and what the recycling probabilities are likely to be in different parts of the world when it reaches the end-of-life. It is much more adventurous when you are dealing with something that is going to be in service for 15 or 20 years" ... "the two things that tend to come up when you think about longevity is, if it uses, if it's something that uses electricity then extending it's life will be an environmental benefit only if the electricity use is quite low. If you extend the life time of something that is a high electricity user, the overall environmental effect is probably going to be negative."

5.4.1.5. Tools for the job

The decisions that have been discussed so far in this section have largely been strategic decisions; the earlier that the decision is made, the more affect it has on the whole product, the whole product range, the whole business, the whole world and so forth. It was found that all of the tools that were used to make environmental decisions were:

1. designed only for the post-specification stages of the design process; and
2. for the use of designers, for specific product design issues.

These tools fit broadly into three categories, which can be listed chronologically (in order of their use throughout design) as:

- assess: where an analysis of the product is carried out, either by means of a detailed LCA or by carrying out an abridged LCA (ALCA). Due to the amount and types of data required, analysis is generally done on an existing product.

- report: where the results of the analysis are presented in some form to highlight environmental concerns in the product.
- prioritise: where the report is considered and priorities are set for design decisions to be made about where to begin to affect environmental design alterations in the new product.

These three stages were echoed by one of the survey participants, but with a further suggestion of the report tool being used as a means of communication between the design function and higher management, thus ensuring an input to future product specifications.

"You need three types of tools. You need something that makes a very general assessment and so I think that means some version of Life Cycle Assessment, probably streamlined because that is going to be more feasible. You need a good technique for presenting the results of that, maybe not in their full detail, but at least the principal results to everybody you can think of: the design team; management; the other people in the Corporate staff. And you need some way to prioritise the recommendations, both because that is a help to the design team and because it shows them that you know that they have other concerns as well; it helps to validate your existence. Now given that you have those three pieces my suspicion is that exactly what those pieces are is probably not too important."

Assess - perhaps the simplest form of assessment possible is to break down an existing product and consider the environmental impacts of each component part, and the product as a whole. This process generally uses experienced designers to carry out a tear-down[10] analysis on an existing product and weigh this against another product or against the company's environmental criteria. The process was reported as being useful both as an educational aid for designers, to see exactly what features of the product were affecting the product's environmental impact, and also as a method of feeding experiences from existing products directly into the concept stage of the new product development. Some companies had recycling/refurbishing plants, which were often used to feed end-of-life experiences to the designers.

"At the concept stage where you are educating the designers, how can the designers and engineers be familiar with what's required at the end of use stage? So we do tear-downs of other companies' products, learning from other manufacturers and looking at our own products."

"I work with the recovery centre. There's a gentleman up there that I work with, and we have established a formal process where we take a product up there, and we do a tear-down on it and he writes off a report that really talks about the good, the bad and the ugly basically and makes recommendations."

Designers need to know about how to include environmental considerations into the design of their products, but are generally given no extra time in which to do this. Given the very tight time constraints that designers were reported to be under, many expressed the need to have quick and simple methods of deciding the environmental

[10] tear-down - disassembly exercise where disassembly timings, materials types and environmental design features are recorded and analysed

impacts of their products. In the companies that had an environmental training programme in place, the training team would first take an existing product and carry out an environmental assessment on it. The next stage would be to work through the assessment with the design team and teach them to use an environmental design decision-making technique. The timing and timeliness of this process was said to be key to its success.

"We want to streamline the whole process so that rather than doing one of these 'for six months everybody goes slowly and tries to get everything right' operations. With our streamlining matrix approaches we really can do it in about a day or two with the design team - and you would get a day or two with the design team. But, six months you might get once, you will never get it again, and you have probably heard this at other places" ... "We have found that a day and a half, two days, you can get that every time, and you can get an awful lot done. In fact I would claim that there are very, very few decisions, maybe none that the designer would make differently having had a six month assessment, or a two day assessment."

Techniques such as LCA were considered to be too expensive, cumbersome and inconclusive for designers to use in their everyday design roles. If an LCA had been done on a company's product, it had usually been carried out as an exemplar study by a specialist department within the company. Almost all of the design managers and environmental champions were awaiting modular LCA techniques, where the designer would be able to select off-the-shelf LCA modules and piece them together according to their product's intended features. Until this day arrives, LCA's were said to be confined to the research and development laboratory, not the design room.

There was therefore a preference towards ALCA's (or 'quick-and-dirties' as they were known). These abridged techniques varied from one company to the next, but often consisted of little or no mathematics for the designer, the philosophy being that there were presently so many five minute environmental improvements that could be made, that simple rules of thumb would be sufficient to make a significant start in improving the environmental profile of a product in a very short amount of time. In the cases where the designer was required to deal with numbers, this would be no more than a simple addition of the scores awarded to product features, based on a pre-calculated eco-points system, designed to give the designer a comparative score between a choice of two possible solutions. Where an eco-points system was used it was, in all cases, an internal company method of considering the environmental impact of a product designed purely for comparative analysis, and did not pretend to be a definitive environmental load unit.

"We use the integers between 0 and 4, and nothing else, and that helps us do it quickly because if we had to argue about 3.1, or 2.6, it would take longer, but the advice doesn't change. So one way to streamline is to limit the number of possible choices."

"Very few of the designers' decisions are based on quantification, they usually do not have a choice of using 2kg of something, or 1kg of something" ... "our experience has been that almost anything we can think of that is actually going to be implemented by the design team is qualitative information not quantitative. And this

plays into the fact that you can pretty efficiently give a qualitative assessment in a short period of time and a quantitative assessment takes much, much longer."

Report - a report was produced as a direct result of carrying out an environmental assessment on a product and was said to consist of both factual results, (eco-point scores, graphs, etc.) and qualitative advice so that the causes of greatest environmental concern could be easily identified. Where some companies were satisfied with the fact that the report was produced and had managed to capture some key environmental concerns for the product design, others saw the report as a way in which to influence future designs by acting as an input to the product design specification. Others commented on the way in which they saw a need in the future for environmental assessment reports to be integrated into existing tools such as computer aided design for use by the designers.

"So we are a long way off having a perfect tool which would effectively link into our existing CAD tools so that engineers would not have to put in much extra effort to generate a report. But we'll keep nagging, reminding and analysing on a day to day basis because this is the only way really to effect change, but we hope we will be able to effectively run the report on the whole product and say how much better is that than the one we based it on."

Prioritise - the final desired stage of environmental design decision-making was described as being the prioritising of the product's highlighted environmental impacts, so that the design team could make a start on design improvement. The prioritising stage of decision-making for the environment would involve taking the product's environmental impacts from the report and placing them within the constraints of the company. So for example, the environmental report could show up a cable made out of PVC as being an area on which to focus environmental design attention for a product, but for reasons such as cost, or materials supply, this may not yet be a priority for the company. This does not mean to say that this particular environmental concern would get ignored forever more, instead, the prioritisation process would move the concern to one of supplier liaison, or customer education, if it were to mean an increase in cost.

"I don't worry very much at the moment about things like nickel, I do prioritise a bit, but I do worry more about things like Cadmium. Cadmium is an interesting issue with us because we are obliged, for some military contracts, to supply components with Cadmium plated screws, washers etc. and we are obliged for other projects not to supply Cadmium. But here's an example - to supply a material that we would love to get rid of, in fact, getting rid of it would reduce inventory. It could easily be replaced by stainless steel, the problem is that [the customers] *who write* [the product] *military standards haven't got around to saying we can do that yet."*

"The objective is to try and develop some tools for the designers so if they change from one polymer to the other they can see what really happens, what's the effect at the end-of-life and what does it do up the supply chain. At the moment there isn't anything that gives us that."

5.4.1.6. A lack of tools

Many of the participants mentioned that there was a lack of suitable tools to aid the design of less environmentally harmful products, particularly in the very early stages of the design process. It is ironic that although there was a recognition that a very high proportion of a product's environmental attributes were decided in the pre-specification stages of design, most of the existing tools appeared to be aiding the consideration of environmental attributes much later in the design process. It appeared then that there was a need to provide up-front tools for the decision makers in the pre-specification stages of design.

"Life-Cycle Analysis software. Generally that requires extensive knowledge of not only the materials involved, but also the amounts of materials, and that is information that we don't usually have early in the design process. By the time you have the information it is late in the design process, most everything is frozen!"

"I actually think we are lacking some tools. We are part of a [research] *programme at* [a university] *where we have in that grouping raw material manufacturers, component manufacturers, electrical/electronic goods manufacturers, dismantlers of electronic goods and waste disposal. The reason we are together is that we believe we don't have all the tools we need."*

The inclusion of designers, or more design influence in the pre-specification stage of design, and the encouragement of communication through product assessment reports were felt to be two key areas where environmental design expertise could be ensured at the very early stages of the design process.

5.4.1.7. Hypothesis 1 - summary

This hypothesis argued that the timing of environmental decisions is key to environmentally conscious design. Furthermore those environmental decisions made in the pre-specification phases of design were argued to have a greater impact on the design, due to the people involved in making these decisions and the opportunities offered by making decisions before too many constraints are imposed onto the product design.

The data recorded for this hypothesis have shown the use of various functions of a company towards making environmental decisions in the design process. A pattern is emerging that describes the types of environmental decisions made at different times in the design process, and the affect that these decisions have on the environmental profile of the product.

It has been shown that the very early design stages, particularly before the product design specification is drawn up, are those which influence the environmental profile of the product the most; however there is a distinct lack of tools to aid this area of decision-making. Hoffman [42] talks of the problems of carrying out environmental decision-making in the early stages of design due to the lack of data available at these stages and the fact that most existing tools are data dependent. There is an opportunity to improve the level of environmental understanding in the pre-specification stage of the product design process, by including experienced designers in the discussion, rather than leaving pre-specification design decisions to marketing and design management, which has been found to be the norm - this was also evident from the pilot study, where even design decisions that were supposed to be made by engineering designers (as defined by the company's manual) had already been made in the pre-specification stage of design! Another way in which to aid environmental understanding in the pre-specification stages of design would be to consult the environmental analysis reports from previous products.

Detailed technical analysis tools are not favoured during the design process due to the time taken to execute them and the level of expertise that would be required of the designer. Instead, there is a leaning to more qualitative approaches to environmental design decision-making, which are argued to give a rough-cut solution in a vastly reduced amount of time. Graedel and Allenby [43] develop an abridged LCA technique providing a simple scoring method that can be used by designers to quickly assess the environmental priorities in a product. A target-plot also provides a graphical picture of which areas of the product to concentrate effort on first.

Environmentally conscious design tools and techniques used in the design process fit into one of three categories: assess, report and prioritise. Advanced companies tend to have a tool or technique that addresses each of these three stages in turn, so the possible environmental improvements that result from assessment exercises are properly documented and considered by the design team.

In the search for evidence of environmentally positive decision-making late in the design process (e.g. detail design or later), only a few isolated cases could be found. Decisions such as packaging can be made that do not have to be made early in the design process, though decisions on distribution and servicing, for example, are typically already significantly constrained by the time of the PDS.

5.4.2. Awareness and enthusiasm

Hypothesis 2

Enthusiasm is key to environmentally conscious design; involvement of decision-makers who have the enthusiasm to find solutions to problems is more important than detailed environmental subject knowledge.

This hypothesis argues that an enthusiastic approach to environmentally conscious design is more important than environmental subject expertise. Many companies that are attempting environmentally conscious design have a key person, referred to as the 'environmental champion', who drives the environmental design activity within the company. It is argued that whilst there is a need for specialists to carry out detailed environmental calculations, environmental champions need only to know where to go to find this knowledge, and not necessarily to possess it themselves. An environmental champion is defined as someone with: the ability to identify and involve the creativity inherent in all product designers; the enthusiasm to encourage designers to integrate environmental decisions into their designs; the skills to communicate environmental requirements to the whole company; and the knowledge of where to go to for more detailed and specialist information if the need arises.

5.4.2.1. An enthusiastic driving force

Every person interviewed could identify at least one individual within their organisation who fitted the description of environmental champion. This champion generally sat in one of two places in the company: either within a business, interfacing on a daily basis with design teams; or at corporate level, where daily contact with designers was less common. The role of the environmental champion varied slightly from company to company, as will be revealed in this section, but one common factor that existed was the fact that the champion was the driving force, acting as a constant reminder to everyone that environmental considerations had to be made in design.

"We have to keep reminding people. The design training is still going on, I don't think it will ever be complete because new ideas come up" ... "we get to hear what other people are doing, new ways of going about things, other people's experiences and so on."

"keeping nagging, reminding and analysing on a day to day basis because this is the only way to really effect change, but equally one which we hope will be able to do effectively."

As mentioned above, the placement of the environmental champion within the company varied across the survey sample. The most common model, certainly amongst those companies who had been practising environmentally conscious design for the longest, was to place the environmental champion within the management of each business. This was said to enable:

- direct communication vertically in the management hierarchy, enabling experiences and advice to pass both ways between management, the champion and the designers; and
- horizontally across the business units, so that all environmental champions could communicate common experiences to each other.

To enable communication between these environmental champions, two companies had established company-wide environmental steering committees.

"Within each one of the design groups you had another person who was responsible within that design group for the design for environment attributes that flowed through his module, sub-system or system. So that person was within that management community to help drive the design for the environment attributes. He could talk to his peers about trying to make things happen the right way, so that you had a hierarchy within the product programme."

"What you have is a design engineer, in a design community, who has a reputation within the design community, driving environmental considerations into the design community and in a language that they understand so that they can sympathise with what he is saying. Whereas if EH&S walks in the door, they are going to tell you to go back and sulk; they are going to do whatever they want to do because they are not in your organisation. So, that was the logic of my position."

Two main reasons were cited for environmental champions to be from middle management: firstly, because top management were seen as being too far removed from the design function to be able to relate to designers' needs and ideas; secondly, because enthusiastic designers who tried to effect environmental change in their product designs could only get so far before reaching the barriers of cost, respect from fellow designers, and from top management. Enthusiastic designers were highly valued for environmentally conscious design integration, but were said to work better without too much of the responsibility for ensuring design-wide environmental decisions.

The enthusiasm of the environmental champion was felt to be of great significance. Many of the champions that were interviewed were in their positions of responsibility because they pushed themselves there at the very beginning of the company's efforts with environmental issues.

"I don't want to sound arrogant but I was the first person interested in it. If you like it was a personal crusade at first and that was two and a half years ago. What we did was, I thought we should be going down that route for several reasons, one was that it was the right thing to do for an organisation. Particularly in a young growing organisation there was the opportunity."

One of the best ways to enthuse designers about incorporating environmental ideas into the design process was said to give them real-life examples to consider. Many of the companies that had remanufacturing/recycling facilities used these regularly to show their product designers around. This way designers could see for themselves, the need to design in a different way, if someone was going to have to take their products to pieces at the end of their working lives. To see with their own eyes that there was a real need to design differently was said to give them a greater enthusiasm about what decisions needed to be made for environmentally conscious design.

"I took them around the floor [of the remanufacturing facility] *and being good mechanical designers, I could see there were a few lights going on but I mean, they picked up really quickly on what they needed to do" ... "not to mention the fact that they really enjoyed it. I mean, people that are interested in mechanical design, it is almost like they are in a toy store when you show them something like that!"*

Enthusiasm from designers towards environmentally conscious design was rarely seen as being a problem, indeed in some cases it was the designers who played the lead role in the relationship between design and the environmental champion. In many cases young designers were credited with having the most enthusiasm towards environmentally conscious design due to the increased exposure they had had to environmental issues during their education.

"Generally design teams tend to be made up of fairly young engineers and the young engineers see this as an important thing to do."

"The good thing about environment is that it is something that they can personally relate to, probably more than some of the other issues and therefore it does get attention."

Environmental champions saw it as their role to identify this knowledge and enthusiasm in the designers and take advantage of it by involving them in workshops and environmental pilot studies.

5.4.2.2. Involvement in design

Having received a product design specification with environmental criteria written into it, designers would need guidance to meet the specification. The environmental champion was said to play a very important role as a provider of information to designers. If the champion did not have the answers to designers' queries (usually specific and detailed issues) it was their job to go out and find that information. As the environmental champion became known within the company they built up a reputation of being the focal point for all environmental issues.

"They would start off by coming to see me. I'm not saying that I could answer the problem for them, but if I don't know the answer I know a man who does and we often work together to solve environmental issues. One of the key ones at the minute seems to be not a design issue but it's being handled within the engineering department, and that is timber and the certification of timber to FSC guidelines as proven as coming from a well managed source. So we are currently working on that with the guys over there to meet the 1999 [conformance] *deadline, that's coming from our customers."*

"I do get calls every week from at least one of the divisions about something, whether it's a mercury switch or a battery or lead strip, codeine on glass; it's really bizarre, but all these sorts of queries come to me. I don't know what the end answer is, but I know where to go to ask and where to direct the questions."

Rather than simply providing environmental information to designers on request, many environmental champions were proactive, and keen to become involved in the actual designing of the product, so as to be able to offer advice along the way and also to learn themselves about the product design.

"I said 'please involve me in your design reviews', that is the easiest way I could see to get something done and make some positive step in the right direction. When people are having a design review they are going through the whole design or design criteria and I could go through and see if there are any areas where there are environmental issues."

Being involved in the design teams in this way ensured that lessons learned from one product design could be carried over to other and future product designs, especially in the case where an existing product was going through a facelift; if it was designed previously with the environment in mind, all of the design team's efforts would be in vain if someone was not there to ensure that the product at least retained (and at best improved) its environmental profile.

"I have counted up I think about a dozen products that have either been released or are being put into this box and I need to keep on top of those people to make sure that they don't take a step backwards. Like say they invent a new plastic piece because they want to give it a little different look and they don't put the ISO marking

on that piece, you know, that is a place where we can take a step back so, you have got to keep the pressure on."

"But we have also got within our regulatory team a couple of guys, managers, who are entirely responsible for ensuring that from our existing product range and anything new, each new product gets taken into the environmental fold."

5.4.2.3. Culture and communication

Depending on how long the company had been practising environmentally conscious design it seemed that there was a link to the amount of effort that was required to change the thinking of the designers towards environmental issues. Generally it was thought that designers would pick up the basic principles of environmentally conscious design after the first couple of encounters with the environmental champion (via training courses or product assessment workshops), and after the next couple of exercises these principles would begin to stick in their minds.

"The ideal is that after you have done one or two with the design team, they start to embed it into their software and into their thinking, and they will get at least 50 or 60% of what you might recommend automatically."

After their initial reservations about environmentally conscious design had been alleviated, designers were said to drive the integration of environmental issues themselves, wanting to become involved in more workshops and into deeper levels of information about the environmentally driven changes they were making.

"The biggest problem was getting the people at the right level to listen and understand and to be sold on it. It was like pushing a very large rock up a hill and once I got to the top of the hill it started to roll and I didn't have to do anything it's hurtling down the other side now and there are loads of people jumping on the bandwagon! We are almost overwhelmed now and have the other problem in that everyone wants to have their finger in the environment pie."

"It was like there was this ground swell of interest, you know. Particularly in some of the plants, you would find people like this, their jobs were in finance or something like that, but I mean they kind of come out of the woodwork and they wanted to help with this, you know. They would really be completely out of what they should have been doing, but they were so interested in this decision that it consumed them."

There was an awareness that changes were necessary across the business if environmental ideas were to become both universally accepted and feasible. These changes could not, it was recognised, be made all at once, instead they had to be made subtly and carefully. Everyone has an affect on the environment and it seems that everyone also has an opinion on it, based largely on emotions, rather than knowledge. If changes were made too quickly to the nature of the organisation for environmental reasons, the company would run the risk of upsetting people's emotions, which could result in negative opinion of changes being made.

"So you are talking about a culture change, you are talking about a standards change, you are talking about design practice changes, you are talking about tremendous changes, and not all those details have been worked out over the last few

years. So you have to innovate, convince, do it, and there will be some exposure, we will have some shortfalls. But we will just keep trying."

"I would say that once you convinced them that you are not going to have a strong negative impact on some of the other things they think about, then they are quite receptive."

In every company the role that was attached to the environmental champion was one of help and advice. This meant that they were a real focus for designers and other members of the company to contact for information. Due perhaps to their enthusiasm (which was often the reason for them being in this role) many of the environmental champions were pro-active about sharing this information, rather than giving it out on a need-to-know basis.

"My role at the moment in the design process is as a supplier of environmental expertise."

"I go to [our company's] *symposia and listen to the people that are trying to influence designers. I am more involved in taking the good deeds and efforts of the ECP community and trying to communicate that internally to our own work force and marketing people so they can influence the customer directly; and externally to academia and to industry, which is part of our corporate policy, as well to share our knowledge with others."*

It was stressed that it was extremely important for the environmental champion to communicate with the designers and all other functional departments in the correct language; there was a danger of turning potentially interested people away from the cause if they were blinded with technical jargon. This was said to be unnecessary and that all issues could be dealt with in straightforward language - indeed this would encourage people to take ownership of the issues and want to tackle them themselves.

It was also mentioned that when talking to employees from other departments, such as marketing, there was no shame in putting environmental objectives in the language of marketing and cost-savings.

"We were able to set some design rules, about 'here is what we want to do' and everything was very leisurely paced and we have good quality discussion about it and you know, I think the condition was that if it slows us down or it costs more, you know, we are really going to have to think twice about doing this because we still have all these other requirements."

"We are getting prompted from that angle now, 'For God's sake guys make sure it's right, we don't want bad PR and financial liability!' and I'm finding it a good angle to come from. We've gone from a strategy of 'yes, it's there but Colin will do it' to 'Colin does it but he's got a gang of other guys who he's facilitated to get on with it'."

Many engineers see 'the environment' as the fifth in a chain of manufacturing philosophies that have been emerging over the last twenty years; these five philosophies being cost-quality-time-flexibility-environment [97]. Another approach to driving environmental considerations within the design process was to take a total quality approach and integrate environmental issues along the same lines as quality management.

"He took on making sure that it happened. He did a very simple thing, he'd tried for ages to get over the message about total quality and he took the opportunity of re-launching total quality with launching environmental protection and managed to get people to see the parallels, partly due to the fact that BS7750 and BS5750 have very similar procedures, partly because it's the same old thing, design for environmental protection is just like design for production. And with total quality we've always said that once you've got 80% of the people you might as well give up the 20% you'll never get through to. But Eddie reckoned he managed to get another 5% of the people he'd never got through to before by attacking it from a different angle. He's pitched this all over the place and several people have taken up his enthusiasm and managed to do something similar."

A contradiction to this view of quality being a good vehicle with which to drive environmental considerations into design was the opinion that quality issues were an unwelcome addition to the design process. Environmental issues, on the other hand, were seen to add interesting detail to the designers' jobs.

"It's interesting how green things turn people on unlike quality which turns people off. Everyone can identify with it and they can feel good about talking about their work when they get home."

5.4.2.4. Education

All environmental champions had a role in educating designers about how to carry out certain environmentally conscious design techniques. One environmental champion advocated the use of team exercises and absolute honesty that the solution to the exercise was not a pre-scribed answer. This led to the designers feeling ownership over the exercise and much more motivation to getting the best answer possible.

"It was amazing, they were in their little huddle and nobody could tell them what to do, but they had a presentation where a colleague of mine and I talked together about what we were doing and the reasons why. They realised we weren't telling them how to do their job, we were actually setting them a challenge. They realised it wasn't somebody going to come up and interfere and tell them how to design something but basically we were throwing the door open saying, 'we don't know the answer to this'; they really latched on to it."

Other companies favoured a more passive approach to educating their designers, providing a steady supply of information through their internal publishing and conferencing systems.

"The designers would have environmental awareness training. We do not have specific design for environment training programmes but we do have in effect knowledge sharing. So a technology group would meet together and someone would give a paper on a particular subject, I have given one on design for environment in

[our] *industry. Through the various meeting groups we exchange knowledge, but there aren't any courses specifically. The group leading our technology function for Life Cycle Analysis have been to a couple of training courses on Design for Environment, actually to get expertise themselves."*

Designers and design teams would be encouraged in this case to write papers about their experiences in carrying out environmentally conscious design, and the paper would be discussed at a group meeting, when problems could be shared and solutions brainstormed.

5.4.2.5. Difficulties

The environmental champion has an extremely evangelical task, ensuring a level of environmental awareness across a whole range of employees, and then attempting to constantly raise this awareness. A great deal of time is spent with certain people, not merely from the design function, but other departments that contribute to the design process. Two participants spoke of frustrations when having invested a large amount of time bringing people up to date with the level of environmental awareness within the company, only for those people to leave the company shortly afterwards.

"There is the fast growth, rapid turnover of people, you know. I mean I spent a lot of time trying to get in with the marketing people and it turned out that in the course of a month, two of the three major marketing people in the business left the company, and they ended up hiring replacements ultimately and it took me three months to get on their calendar."

Another difficulty that was mentioned by many participants was in getting middle management to commit to environmentally conscious design, and even if they were committed, it was difficult to know how to involve them in the physical designing of the product.

"I think probably what I would do is try to figure out a way to get the attention of the middle managers on the issues. My perception isn't that we are short of tools, or short of enthusiasm in the design teams. I don't think we are short of the visions, but the implementation is always hard work."

5.4.2.6. Hypothesis 2 - summary

This hypothesis argued that enthusiasm is key to environmentally conscious design, and that environmental issues need to be driven by an enthusiastic person, known commonly as an environmental champion. It was also argued that awareness and enthusiasm were more important traits in an environmental champion than specific environmental subject knowledge.

The data collected showed that there was a need for an enthusiastic person to drive and remind of environmental issues in design. Every company could name at least one environmental champion within their organisation, but there was a difference across the survey in the position of the champion. Where some companies favoured placing their environmental champion very close to the design function, others tended towards keeping their enthusiasts at corporate level.

Environmental champions generally saw themselves as being very enthusiastic people, most of whom had arrived at their jobs due to their personal interest in the subject when it first appeared in the company. This does not mean that enthusiasm was the only criteria for an environmental champion, it was said to be difficult for people lower down the organisational hierarchy (such as engineering designers) to become environmental champions, due to the fact that they would encounter too many barriers from people higher up in the organisation. For this reason, middle managers were often chosen for the job.

Provided that the environmental champion spoke the correct language (usually the terminology of engineering design) and gave stimulating examples, enthusiasm was not seen to be a problem in the design team. The environmental champion was seen as being the conduit for all environmentally-related enquiries, similar to Lenox and Ehrenfeld's environmental catalyst [69], and was not expected necessarily to have the answer to every query straight away, but to know who to go to for a suitable answer. It was the job of the environmental champion to ensure a level of sustained awareness and motivation towards environmental issues across the whole business, the ultimate goal being to gradually change the culture of the employees, so that they may begin to consider environmental issues as everyday decisions.

All of the companies had identifiable environmental champions and the need for such a person was regularly stated by the non-environmental champion interviewees. Both the environmental champions and the non-environmental champions identified enthusiasm of environmental champions as significant.

5.4.3. Top management commitment

Hypothesis 3

> Top management commitment is key to environmentally conscious design; without top management commitment (manifested through the provision of resources; company environmental vision statements; the commitment to achieve recognised environmental standards; the support of environmental training schemes; and corporate membership of external environmental forums) environmentally conscious design does not become an integral part of the design process.

This hypothesis argues that the integration of environmentally conscious design into the design process is reliant on top management commitment, defined here as being the drive or approval at corporate level for environmental issues to be integrated into design. The way in which top management commitment may be identified in organisations is through:

- company environmental vision statements;
- the provision of resources;
- corporate membership of external environmental forums;
- the approval of environmental training schemes;
- the application for external environmental standards; and
- the setting of internal environmental standards.

5.4.3.1. Standards and regulations

One of the key initial motivators for environmental issues to become integrated into a company's philosophy is legislation. The participants of this survey fell into two categories when questioned on the affects of environmental legislation on top management decision-making. Firstly there were those who were just managing to come to terms with environmental legislation and were managing to react to remain in compliance with issues. Then there were the proactive companies who recognised the merits of staying one step ahead of the game and making changes to their design process before it was decreed by legislation.

"The strategy has been that whenever possible we try and influence the legislation so that we have a go at trying to get it the way we want it."

"I guess I have to say Tim, that probably our environmental plan, in the past, has been more reactive than proactive and has been driven an awful lot by the government dictates on energy, and on some of these other items like CFC's etc. Now we have taken a proactive role in the sense that industry has got together and negotiated with the environmentalists about what the next set of environmental standards should be."

The merits of staying ahead of legislation were cited as being the ability to use a proactive approach to remain ahead of competition and where possible to prevent legislation from ever even arising.

Many people saw the short-term future as holding increasingly strict legislation, as global legislation develops towards consensus. It was thought that companies who are presently staying out of legal troubles by trading in areas of the world where regulation is weak would run out of places to hide.

"I think the people that don't design that way will eventually design themselves right out of business. And so everyone is looking....well if you are looking to do business for the next five years in Europe this is an important thing, and if you want to do business for the next ten years in Asia and North America it's important, and in the next fifteen or twenty in the rest of the world it is going to be important."

As well as complying to legislation, many companies have been encouraged by their top management to align their products to one or more Ecolabels. This highlights the second and third motivators from Section 2.1.2 for carrying out environmentally conscious design - competition and customer requirements.

"We have recognised the need to have an environmental strategy from a legal point of view so we meet all the legislative requirements and then more and more now we are being asked to look at the Ecolabels simply because our sales force are saying we need to have products which are environmentally friendly to have an advantage. So that is included in our portfolio now and we have the corporate environmental group as well."

There were also moral reasons behind complying to Ecolabels. Companies were beginning to ensure that their suppliers were also complying to the same Ecolabels that they were adhering to.

"What we are saying is that all our new products that we are going to be supplied with downstream, we are putting in the business case for them to meet Blue Angel and by January 1998 they must have [our internal standard] *or an equivalent EMS . We've got a view that says if you are going to do this, particularly if you are going to use it as a differentiator and effectively try to take the moral high ground, you have to be squeaky clean."*

Internally, some companies were beginning to set their own standards and measurement systems in place as illustrated by the last comment. Internal environmental standards were always initiated by top management, the reason for their initiation being to ensure that the company was operating within the correct legal framework.

"We also have an environmental protection plan largely being driven by keeping the Managing Director out of jail because of the Environmental Protection Act."

"In other words environment isn't something the environmental manager does, it is something that is part of every function and part of our operation world-wide. That commitment was formally taken on by the board in February 1995 and we have been implementing that strongly ever since throughout the company."

5.4.3.2. From where the commitment comes

The majority of the participants agreed that top management commitment was necessary for initiating environmentally conscious design with a company, and many also believed that sustained and increased commitment was necessary for environmentally conscious design to develop within the company. One senior manager made the comment that it was extremely important to constantly recheck the company position in terms of environmental performance, and to operate on a system of continuous improvement.

"I don't think you can demonstrate environmental affairs leadership if all you do is minimum requirements all the time, really that's just the same as everyone else."

This particular company wanted to be seen as one of the world leaders in environmentally conscious design. Some companies placed a senior manager in each business unit of their company to steer the environmental efforts of the business and to maintain commitment to environmentally conscious design.

"Within each product division there is an 'Environmentally Conscious Product Strategy Owner'. That is quite a senior executive position, it is almost like a figurehead but they provide that level of focus and commitment within that organisation and product group. They have the responsibility for every year issuing an operating plan, what they propose to do on environmentally conscious products, how many product assessments they will make, what sort of new initiatives they will take, goals, targets etc."

In some cases, it was reported that the company had been lucky enough to have had committed top management from the outset, meaning that environmental issues were an inherent part of the business operations from an early stage. Examples were given of how the chairman of the company managed to provide the initial commitment to environmentally conscious design and then identify key people to carry the task on.

"Our Chairman was very conscious of environmental issues and at that point he made us a signatory to the International Chamber of Commerce Charter for Sustainable Development, simultaneously myself and other people working on the ground were conscious that the environment had to be taken much more seriously and in the early 1990's we certainly did some strategic papers."

"I would also think that our top management are very interested in environmental issues. They would stand a little bit more for the product, to have it become a little bit more environmental, and I'm not sure that's the case for all [similar] *companies in the U.S. but there is a true interest in having the product more environmentally friendly."*

There were mixed views about how important top management involvement was to sustain environmental issues, and different approaches were reported. In some cases a corporate group was appointed to steer environmentally conscious design across the company and in others it was said to be enough that top management provided the initial kick-start to environmentally conscious design, but little attention would be paid by designers to anything that was communicated thereafter.

"We have a corporate environment department based in headquarters. They are about six guys who are responsible for making sure we meet legislative guidelines in everything we do."

"We are absolutely convinced that in terms of the policy deployment, if a president, or a chief engineer or a vice president said 'go and do it' probably nothing would happen."

In the above case, it was felt that someone closer to the design team was required to ensure environmentally conscious design considerations were being made, rather like the environmental champion described for the previous hypothesis.

Another view on the level of commitment required to sustain the integration of environmental issues into design focused on the business units as being key, rather than corporate management.

"If the business doesn't embrace it and start integrating it into what they are doing and having their own people do it, then it is not going to go anywhere."

"So it is really up to the business units, and the people within the business units to how they embrace it and how they take advantage of it. So you may talk to one business unit and it says, 'yes there are benefits', but you may talk to another business unit that hasn't seen those benefits and they haven't focused on it."

Although the previous comment advocates the importance of the business' commitment to environmentally conscious design it also highlights the need for communication between businesses, perhaps through corporate direction.

In other cases it was said not to be the top management that initiated the interest in environmentally conscious design; instead a bottom-up push ensured that environmental issues were raised in the company. Interestingly all of the participants who had made these bottom-up commitments to environmentally conscious design through their enthusiasm were now in the position of environmental champion in their companies.

"I think the initial commitment was in a sense bottom-up commitment, but it eventually managed to make it all the way to the top."

To support the view that top management commitment to environmentally conscious design was only needed to provide an initial kick-start, many participants reported that the enthusiasm of designers and the business groups was enough to sustain environmentally conscious design integration and development.

"It's been top-down and bottom-up because the consciousness was out there. In the businesses there was a strong wish that there would be some corporate principles. But they are corporate principles and the actual targets are set by the businesses themselves. They evaluate their environmental effects, they rank them, they decide which ones are the ones they will pursue and they manage that themselves."

"I guess it was top-down to start with. It certainly was at a corporate level when there was recognition late 80's and that really came from things like priority waste streams in Europe. All of a sudden they woke up to the fact of what was on the horizon, that we might have to take back our products. I think we needed that focus first of all that said 'This is what is happening'. Now I think it goes all over the place because corporate can only influence to a certain extent. The product groups themselves are very powerful and Corporate Environmental has a limited command and control, so you've got to do it by a more subtle approach. So it can't be this big command, there are certain things you can dictate, like 'you must have this kind of strategy' but what you do within that is up to the product groups."

5.4.3.3. Commitment to a whole-life approach

Having discussed the need for top management commitment and its effectiveness (or not) in sustaining environmentally conscious design integration, certain conclusions may be drawn. However, those companies who had been practising environmentally conscious design the longest stressed the need to look at the whole story - the design of the whole product life. The types of decisions that needed to be made when beginning to design for whole product lives, or multiple product lives required absolute commitment from top management, on very high level strategic decisions.

"Probably in a big way when we started to design [product x] *I would say we started to think about recycling because we designed that machine on the basis of a frame that could be reused, and twenty years later we are still recycling that machine. So that is when I know we started to design for the environment - so that we could*

recycle. We were doing that before because we've always had recovery of parts ever since we've been manufacturing."

Again, those companies who had been practising environmentally conscious design for longer were hypothesising about the future benefits of carrying out environmentally conscious design. Some participants commented that although many companies were presently co-operating with each other in trying to find environmental solutions to problems, the future level of co-operation may change, as the same companies would begin to recognise the competitive benefits of their environmentally led innovations.

"This is going to be a very interesting field over the next four to five years because if indeed it can be shown that it is very cost competitive, then the co-operation that we see between all these companies may change, because it could be a competitive one. It is hard to put a time-frame on it right now, but I think that will happen, over the next two, three, five years."

"I find it interesting that the Japanese computer manufacturers have turned out a number of patents, filed as design for the environment concepts - more than the U.S. And that probably is a warning sign, right now."

Supporting comments to these ideas of increased benefits from environmental conformance revolved largely around cost savings.

"If you design something with end-of-life in mind it will have value at the end of it's life, as opposed to being something we have to pay £40 to dump in a hole some place."

"I think there is the opportunity for the data to come round and show that if you pay attention to design for the environment, you're going to reduce your costs."

Taking the idea of cost savings one step further, and looking to the examples set by those companies who have been practising environmentally conscious design for longer, a selection of the participants reported that their companies were also beginning to make strategic decisions about the relationship they had with their products, and what they considered to be core business.

"But along the same lines we pay a sum of money every year for a photocopier and the guy comes along and services it. They charge us for every copy that we make. We could charge someone for the length of time he's hired [our product] *from us and I'm sure in a very small amount of time we could recoup the costs from the hire price."*

Not all companies shared this view, however, and some still reckoned on having to pay out more to manufacture environmentally superior products.

"If we were to be a totally green company and design everything with the maximum amount of environmental impact, or minimum impact, if you're looking from the design side, we would become very much a niche manufacturer, appealing to that segment of the market that is willing to pay and buy these kind of products. We have

some of these kinds of products - niche products which are very environmentally friendly, and also higher priced, unfortunately. So far what we see is that to design a green product, the product costs more; maybe that will change in the future, but at this point that's the way it is. So practically, not 100% of the cases, but in most of the cases, to design green is to design high-cost, which means us passing out. Maybe it's not high cost, it's probably worth the investment if you look sometimes at life-cycle analysis, but the American consumer is not very good at looking at life-cycle analysis; their decisions are usually made at the point of sale on the floor and the initial purchase price is 90% of that decision, even though you tell them that over the life-cycle they will recover that cost in three years time. It hasn't had that much weight."

5.4.3.4. Hypothesis 3 - summary

This hypothesis argued that top management commitment was essential if environmentally conscious design was to be integrated into the design process. Top management commitment could be shown through the provision of resources (especially senior management-level time); company environmental vision statements; the commitment to achieve recognised environmental standards; the support of environmental training schemes; and corporate membership of external environmental forums.

The data presented in this section have shown that there are a number of key motivators for environmental issues to be considered in a company, including: legislation; competition; customer pressure; and individual enthusiasm (either from the top or the bottom of the organisation). Three of these findings concur with the literature that is presented in Section 2.1.2. It was agreed in the majority of cases that top management commitment was key to ensure the initial consideration of the environment during design, the reason being that the provision of resources, vision statements, environmental standards and training are all key enablers for designers to be able to cope with environmental decisions and to create a culture that supports such decision-making one of the key motivators. There was some discussion, however, about the level of top management commitment required to initiate environmentally conscious design, and some participants felt that individual enthusiasm was sufficient to have environmental issues recognised.

In terms of sustaining and developing environmentally conscious design, there was less agreement about the role of top management. The split of opinion tended to divide into:

- those who were of the opinion that it was necessary to have top management continually steering and checking up on the activities of the company, and driving environmentally conscious design;
- and those who were of the opinion that top management intervention was less of a help than a hindrance, once the individual business groups and design teams had become interested and taken ownership over environmentally conscious design issues. This second group of people stated that commitment to support from the top was sufficient at this stage, and non-intervention was preferred.

One distinctive group of participants differentiated between the need for top management commitment in environmentally conscious design and top management commitment when considering whole-life issues. Those participants who mentioned it all agreed that top management commitment was essential if issues such as designing for whole-life or designing for multiple product lives were to be achieved, as these were much more strategic considerations where their active participation in decision-making was fundamental.

5.5. Conclusions

This chapter has demonstrated how the three hypotheses, derived from the pilot study in Chapter 4, were developed into a semi-structured interview questionnaire which tested the hypotheses in industry. The survey sample consisted of twenty four individuals, who represented a spread of job descriptions, and thus viewpoints, from the electrical/electronics industry sector. Data were collected by carrying out semi-structured interviews and grouped according to each hypothesis.

The data collected were used to build evidence to test each hypothesis and were presented in this chapter. Initial comments were made about the emerging pattern of the findings. The analysis of these findings will be described in Chapter 6, in relation to other findings from the industry survey, pilot study data, focus group data and existing literature.

The data collected under Hypothesis 1 (timing of environmental decisions in design), highlighted the fact that many functional departments of the organisation are active in the design process, the tasks of which all have an impact at different stages of design. Different types of decisions were seen to be made during the progressing stages of the design process, each type of decision having a different affect on the environmental profile of the design. (One type of decision could be to use snap-fits instead of screws in a product, making it easier to disassemble and recycle. Another type of decision could be to make an electrical product portable, implying the use of batteries and so dramatically altering the environmental profile.) The very early design stages were seen to be those which influenced the environmental profile of the product the most. This was found to be particularly true of the pre-specification stage of design, a stage that was also found to have a distinct lack of tools assigned to it to aid the consideration of environmental issues.

Due to the busy schedule of designers and the time constraints that were increasingly imposed onto the design process, detailed technical analysis tools were not favoured by the majority of the survey participants. Such tools would require a level of expertise that was reported to be non-existent in present design teams. For these reasons, many companies favoured qualitative approaches for environmentally conscious design. It was the general opinion that there are presently enough simple environmental improvements that can be achieved by using quick and simple methods for environmentally conscious design, rather than spend protracted amounts of time and effort on detailed solutions - detailed tools were said to be more suited to research and development departments.

When making environmental decisions, three broad categories of decision-making process were observed: *assess; report; and prioritise.* Followed in the chronological order listed here, a design team was seen to be able to: learn how to go about designing their future products by environmentally *assessing* previous designs; increase the environmental understanding of the company, by producing a *report* of this environmental assessment; and influence future products, by *prioritising* the findings from the assessment in their new designs.

In addition to making environmental reports available to other departments of the organisation, there is an opportunity to improve the level of environmental understanding in the pre-specification stage of the product design process, by including experienced designers in the pre-specification decision-making process. In all of the companies observed, the tools and techniques available for environmentally conscious design were targeted at the designer/design team, yet it was recognised that many of the important environmental issues were decided in the pre-specification stages of the design process. Designers often had no opportunity to influence these decisions as they were not party to pre-specification decision-making.

The findings for Hypothesis 2 (awareness and enthusiasm), emphasised the need for an enthusiastic person to encourage environmental thinking in the design process. This enthusiastic person was commonly known as the environmental champion. The profile of the environmental champion differed from one company to the next, with a general split in opinion about what constituted the champion's role; where some companies placed an environmental champion very close to the design function (argued as being key to the incorporation of environmentally conscious design decisions), others placed them at the corporate level of the company (to drive company-wide awareness and formulate design rules and workshops rather than everyday design guidance).

Environmental champions described themselves as being enthusiastic people. There did seem to be a pre-condition that environmental champions came from middle management, however. This may be due to the problems they would encounter in gaining respect from higher management if they were from any lower down the organisational hierarchy.

Enthusiasm from design teams was reported to be high, provided that the environmental champion addressed environmentally conscious design issues in an innovative way. Stimulating examples and training were seen to be far more effective in gaining designers' commitment than did complicated toxicological language.

Environmental champions were the conduits for all environment-related enquiries; they were not expected to be able to answer every single detailed query immediately, but were expected to know whom to go to for a suitable answer to a detailed problem.

When considering Hypothesis 3 (top management commitment), it was considered to be important to first establish which were the key motivators for carrying out environmentally conscious design. These were found to be: legislation; competition; customer pressure; and individual enthusiasm (either from the top or the bottom of the organisation).

Regardless of which key reasons were reported for carrying out environmentally conscious design, top management commitment was largely agreed to be key to ensure the initial consideration of environmental issues during design, due to the power that top management had to sanction training, materials and resources to the cause. However, some participants felt that individual enthusiasm was sufficient to ensure that environmentally conscious design was considered. Their argument was that there were presently sufficient improvements to be made that were non-cost issues, and that environmental improvements could be seen as being similar to quality improvements, for which there was already top management commitment.

When it came to the issue of developing and sustaining environmentally conscious design, opinion was split between those who felt that top management were required to continually steer environmentally conscious design in the company; and those who believed that individual business groups and design teams would sustain and develop environmentally conscious design themselves. (This may be a reflection of where each company's environmental champion was positioned in relation to the design team.)

When looking to more strategic design issues, such as designing products from a whole-life perspective, or designing for multiple product lives, there was unanimous agreement about the need for top management commitment; business groups and design teams alone could not make such critical decisions, due to the financial and organisational implications that such decisions would have on the company.

The sector-wide survey provided a wealth of rich information which served to test and challenge the three hypotheses. Although a great deal of agreement was observed in the experiences and opinions of the survey sample, there were still some cases when perceptions of the need for key people in the environmentally conscious design process differed. This chapter analysed the interview data with the focused hypotheses in mind and provided the results of this analysis. However, many more issues were raised in the interviews than simply answers to the hypotheses. The hypotheses were used as a vehicle to uncover more detail about companies' efforts in environmentally conscious design integration. It is interesting now to take the results from this chapter and explore further the reasons behind some of the decisions made and opinions of the people interviewed. Chapter 6 does this and further develops the interview data into a theory of environmentally conscious design for this industry sector.

chapter 6

complex data analysis: theory building and model development

This chapter takes the data from the initial data analysis and the tested hypotheses and presents a model of environmentally conscious design integration, based on industry's response. The model, and information within it, is used to build a theory about how environmentally conscious design is being integrated into the electrical/electronics industry sector.

6.1. Research method

This chapter describes the complex data analysis, which took the understanding gained from the sector-wide survey and began to develop a theory of environmentally conscious design integration. The aim of this data analysis was to build a model of environmentally conscious design integration as depicted in Figure 19.

Figure 19 - Research method for data analysis and evaluation

The research was described in Chapter 3 to be of an exploratory nature. This is true of the whole thesis, but to achieve this end it was necessary to carry out an element of explanation. Describing the research in these terms it can be seen that the pilot study was of *exploratory* nature, resulting in the formation of three hypotheses; the initial data analysis sought to *explain* the three hypotheses; and the complex data analysis (presented in this chapter) takes a deeper look into the data in order to *explore* the issues surrounding the integration of environmentally conscious design into the product development process. Figure 20 illustrates the types of research carried out in these three stages.

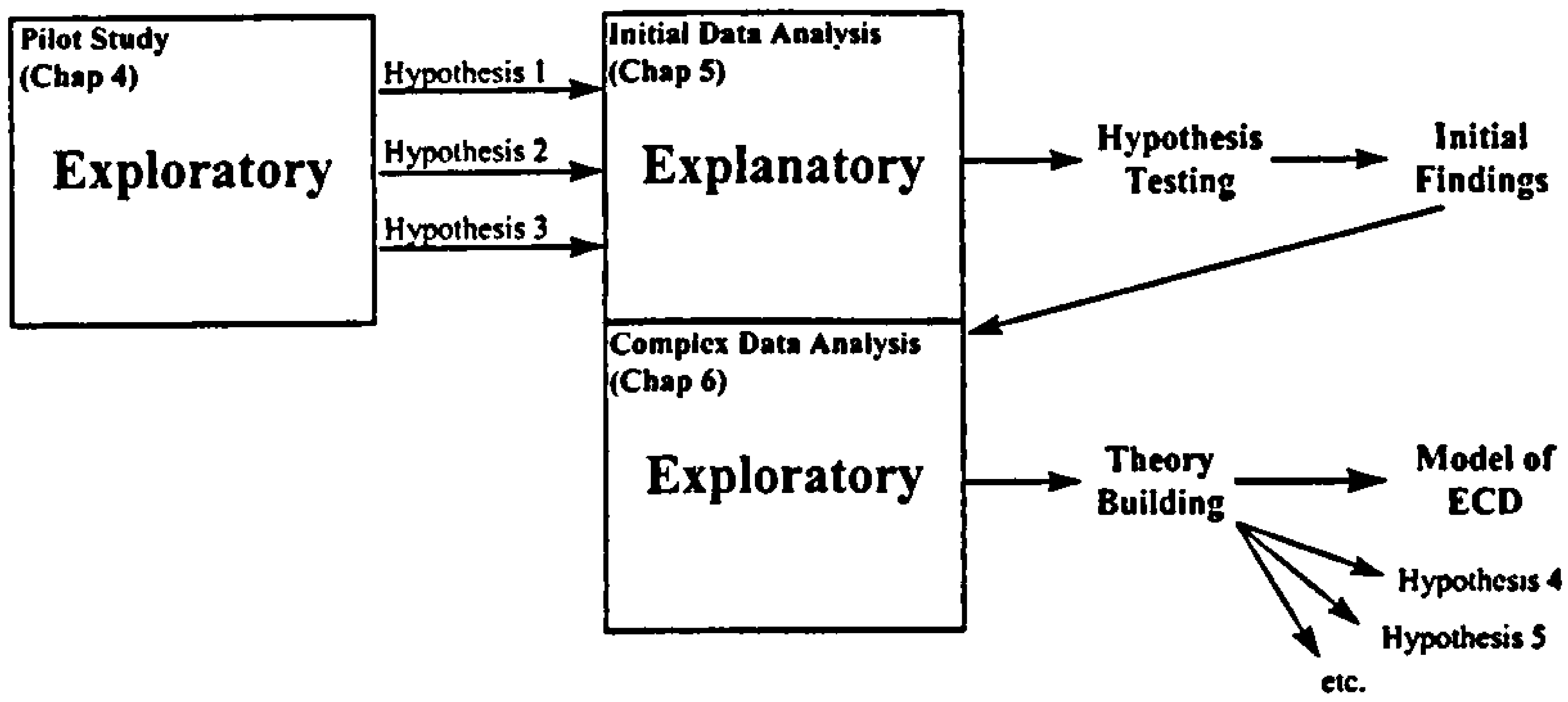

Figure 20 - Research purpose throughout chapters 4-6

The approach described in Figure 20 enabled the focused hypotheses to be supported in the first instance and then more depth to be explored from the research findings, by searching for larger patterns from the data. The qualitative data analysis tool, NUD•IST (described in Section 3.2.4) was used to construct a broader picture and to build a theory from the data collected.

6.2. Data analysis

When carrying out interviews, information was sought about how the interviewees were integrating environmental considerations into their companies' design processes. This was achieved by basing the interview questionnaire on three focused hypotheses. Throughout the course of the interviews, however, many other interesting topics arose, which all added to the broader picture of how the industry was going about environmentally conscious design. All interview transcripts were added to the NUD•IST database ready for analysis.

NUD•IST works by gathering interview data into similar groupings, by means of a coding system. New groupings are formed as the analysis proceeds and a theory is built about the topic in question. By highlighting groupings of similar content the user applies NUD•IST to gradually build up a framework of issues, based on a tree structure.

The starting point chosen for the analysis of the interview data gathered for this research was *'factors affecting environmentally conscious design'*. As interview quotes were studied and grouped together, categories were formed to explain different aspects of environmentally conscious design integration in the companies. Data analysis was honed until the tree structure that emerged from the interview data contained five main categories and seventeen sub-categories. Three out of these seventeen sub-categories related directly to the three research hypotheses for this thesis, as can be seen in Figure 21.

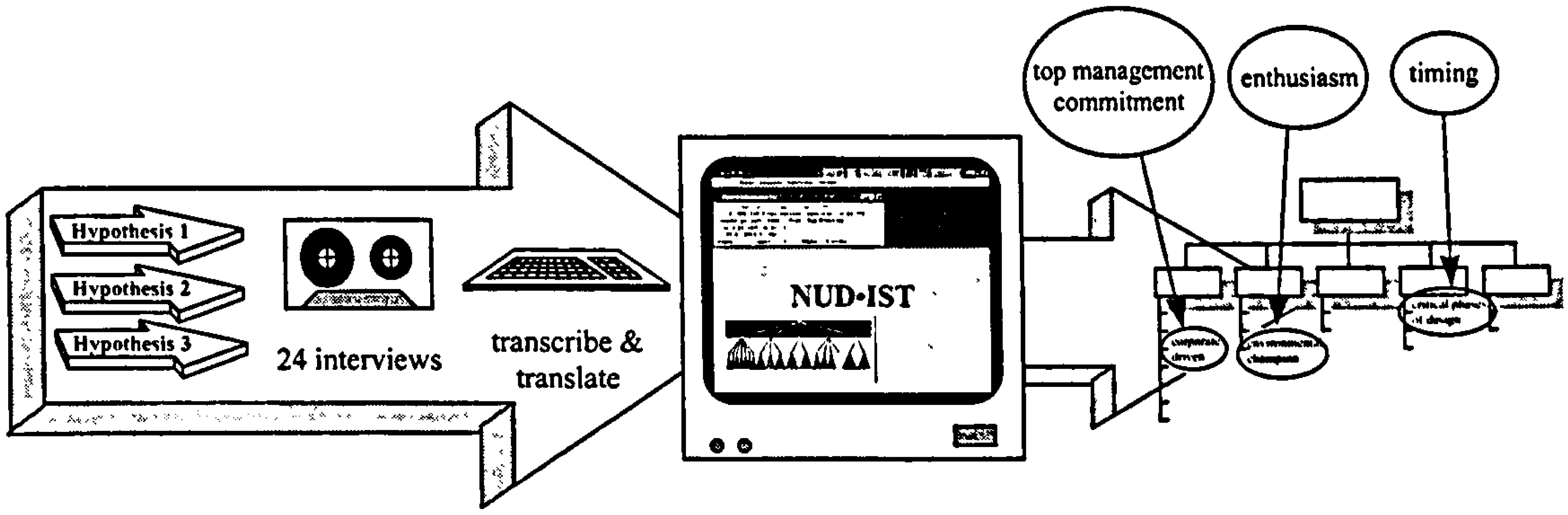

Figure 21 - From hypotheses to research findings

This emerging framework places the hypotheses in a wider context of the data collected, relating them to a host of other issues, all of which are the results of an exploration into industry's integration of environmentally conscious design practices.

6.3. Factors affecting environmentally conscious design

The seventeen factors derived by analysing company interview data are presented in a simple hierarchy in Figure 22. This hierarchy groups the seventeen factors under five main categories, which are explained in turn below.

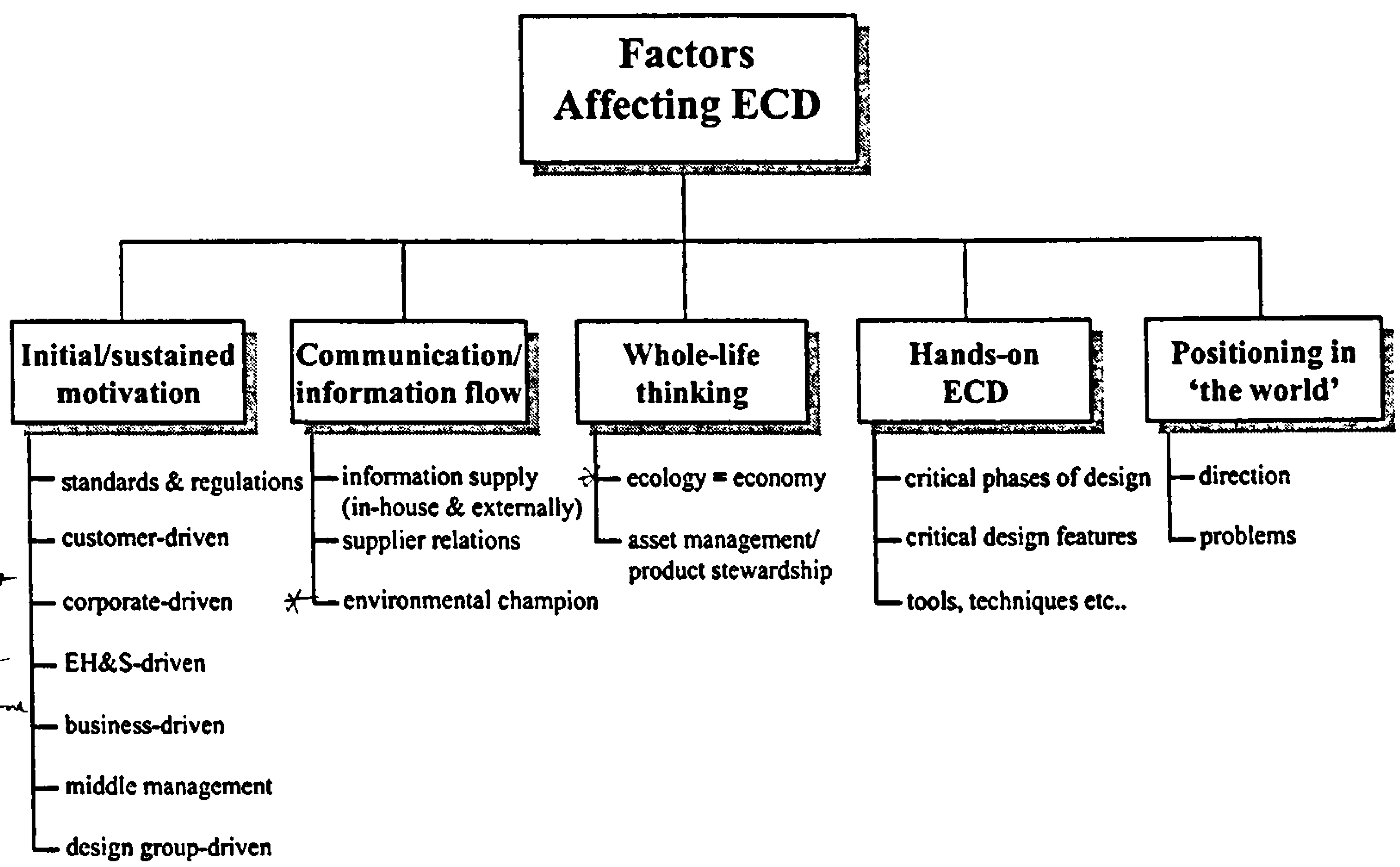

Figure 22 - Emerging framework of factors affecting environmentally conscious design

6.3.1. Initial/sustained motivation

This category groups seven factors that explain what catalysed companies to begin and to continue considering the environment in their product development processes. As can be seen, the factors come from various functional levels of the organisation and also include external influences such as legislation, customer demands and competition.

- **Standards and regulations.** One important motivator for companies to begin to consider environmental issues in the design process was the emerging legislation regarding environmental issues. Besides existing legislation regarding banned substances (such as ozone-depleting gases); packaging laws; and disposal, companies were speculating about the environment-related legislation of the future, such as producer responsibility mandates which would place the liability of end-of-life products onto the original manufacturer of the product and not simply the consumer. Environmental standards such as ISO14000 and the various eco-labels were also cited as being reasons for companies to begin to consider the environment. ISO14000 was cited as being a reason for companies to consider environmental issues in their products due to the demands being made by their customers who were operating to this environmental standard. Eco-labels were cited as being a reason to consider the environment due to the perceived competitive edge that they gave to companies. Many companies interviewed favoured self-regulation over government regulation:

"I believe that it is much better that the companies are self-regulated, and move forward pro-actively on these issues, rather than have regulation drive it, because you will end up with a lot of regulation that doesn't make sense".

- **Customer driven.** With respect to the private market, there was reported to be a marked increase in the demands made by consumers to have products available to them with an improved environmental profile. This concurs with the literature that reports an increase in consumer awareness since the 1980's (see Section 2.1.2). Consumers were said to be willing to go elsewhere for their products if one manufacturer could not offer an environmentally improved alternative. Business customers were also said to be demanding environmentally superior products, due either to the environmental management programmes they were operating in their organisations or due to legislation to which they had to comply:
  *"We have customers now that make product take-back one of the provisions of the contract. The way they do it is not, 'We require you to take this back at the end of it's life', but 'We require you to take it back at the end of it's life **if we ask you to**'".*
  The distinction between the two statements above is that hopefully, the product will be designed to have some value left in it when it reaches its end-of-life. If this is true, the customer can choose to benefit themselves from the product's end-of-life value. However, if the product is *not* designed to have residual value at end-of-life, the customer may give the responsibility of disposal back to the manufacturer. This is a great driver for the company.
- **Corporate driven.** Top management played a large role in motivating their organisation to think about the environment. As with all new manufacturing philosophies it was largely found to be important to have top management buy-in and enthusiasm, if the inclusion of environmental thinking was to be successful. (This factor was explored in greater detail in Chapter 5 as it relates directly to hypothesis 3 - top management commitment.)
- **EH&S driven.** The larger companies interviewed had an environmental health and safety department as part of their organisation, which was often described as being a development of the company's former health and safety department to include wider environmental issues. The very existence of such a department in a company told a story about their level of commitment to environmental affairs. Where these departments existed, they played a role in guiding designers about the environmental impacts of their design decisions. The EH&S departments in some companies ran scheduled training and awareness courses, whereas others

simply assessed each product as it was completed. Due to their detachment from the design function, EH&S departments were often seen as being an environmental policing unit, who would only appear on the scene if a problem occurred, or if someone had not complied to their precepts. This was not always the case, however, and some companies understood the importance of the relationship between Design and EH&S:
"...the more we work with EH&S, the better we understand how environmental science is doing today, and where it is likely to go, and the less likely we are to do things that will create concerns ten or fifteen years later".

- **Business driven.** In some cases it was possible to interview employees from different business units within the same organisation. In these cases there were often marked differences in the levels of environmental commitment and in approaches to environmentally conscious design, from one business to the next. Business driven environmental motivation was generally thought to be of greater value than corporate driven motivation, due to the fact that it was more aligned to the specific products being manufactured by that business, and also because the motivators 'had a face' - meaning that people knew the environmental motivators personally, which had a positive affect on their acceptance of environmental changes.
- **Middle management driven.** Although in some companies middle management were seen as being the group who were the biggest problem to convince that environmental issues should be incorporated into design, the majority of companies reported that they were making an important contribution to environmentally conscious design integration. The majority of environmental champions were from middle management, a position chosen because of their half-way relationship between corporate affairs and the design function. In one organisation a forum had been established for middle managers to communicate environmental design experiences with each other across all business units.
- **Design group driven.** In many cases environmental issues were said to have been initiated by individual designers with the enthusiasm to make environmental improvements to the products they were designing. A great deal of the environmental champions interviewed had arrived at their positions due to their own enthusiasm and drive for the environmental cause, and had been the ones to lead their company to considering environmentally conscious design. The buy-in of the design team was felt to be extremely important to the success of environmentally conscious design. Once designers had been convinced of the need to consider environmental issues they were said to be the group who could affect environmental change most easily, due to their creative attitude:
  "Generally design teams tend to be made up of fairly young engineers and the young engineers see this as an important thing to do" ... "once you convinced them that you are not going to have a strong negative impact on some of the other things they think about, then they are quite receptive".

In conclusion a number of possible catalysts have been identified for companies to begin to consider environmental issues in the design of their products. As well as the external catalysts of legislation and customer demands, almost every level of the organisation can affect a change in the company's awareness of environmental issues.

Companies prefer to be self-regulating, rather than to wait for government mandates. This stance comes possibly from the reluctance of governments to actually produce specific mandates and the desire of proactive companies' to stay one step ahead of legislation. For example, the fact that electrical/electronic waste has been made a priority waste-stream in the EU [6] is often interpreted as a warning by the EU that if companies do nothing to adjust their practices, tough legislation may follow, forcing a set of actions. The reaction to such an announcement for some proactive companies is to attempt to prevent any such legislation from emerging by making changes to their practices. (This was one of the founding reasons behind the formation of the Industry Council for Electrical & Electronic Equipment Recycling - ICER). However, other companies do simply adopt a wait and see attitude.

Top management are a common catalyst for environmental issues being considered in a company, although this was not universally evident from people's comments in the study. The existence of an environmental champion in the design process and an EH&S department are good indicators of top management commitment to environmentally conscious design integration (although EH&S departments are admittedly being increasingly established to fulfil impending legal requirements in the US). At the other end of the organisational spectrum, the creativity of individual designers is another valid catalyst for environmentally conscious design integration. Designers who are involved in everyday product development are ideally positioned to recognise environmental issues that need addressing in their products and, if properly trained, to recognise how to make environmental improvements to their products.

The initial motivation for environmentally conscious design integration will begin to make changes happen in the company. Provided this motivation picks up enough momentum it will have a knock-on effect to other departments and individuals up and down the organisation, so that the motivation for environmentally conscious design may be sustained.

6.3.2. Communication/information flow

This category lists three factors relating to the communication and information sharing that was felt necessary to carry out and develop environmentally conscious design in the companies surveyed. This covers both the internal and external supply of information.

- **Environmental information supply.** The need to effectively communicate environmental information experiences across the design function was seen to be highly important. Multi-functional teams were often cited as being the ideal conditions for designers to discuss and learn about environmental issues in the design process. The fact that an environmental decision could require the inclusion of many diverse functions raised the issue of the design community having to learn a new skill of communicating their ideas in the language of different communities:
  "Yes, it's harder work, we are probably learning the language of finance a bit better as well, notoriously engineers (and I come from an engineering background) really struggle when talking to finance people. So we've learnt a lesson there looking at some of the cost benefits of things like waste management,

particularly when you start to roll in things such as the landfill tax and talking about cost avoidance; it makes the argument more compelling than it was a few years back when all you could say was that there is a corporate requirement to do this".

Communication of the corporate environmental vision to the design teams was reported to be a very important task, and was usually carried out by the environmental champion. Many companies were also running education programmes to ensure that designers would find out more information about the company's recommended environmental design tools; materials selection techniques; and environmental legislation.

- **Supplier relations.** A source of information about environmental alternatives to materials, products or processes that remained untapped by many companies was their supplier network. Only two companies mentioned that suppliers were key people to contact when considering alternative environmental solutions to their product designs:

  "A lot of the information we need on the materials we use, and the performance of them, we get from our suppliers" ... "there is a wealth of information out of material suppliers, that unless you're out there working with them and asking for it, it just sits there".

  This relationship was also seen to work the other way in some situations, where the company would give stipulations to their suppliers about what was considered to be acceptable for their environmentally improved designs.
- **Environmental champion.** The key to successful environmentally conscious design in all companies was agreed to be motivation, which was assisted by the appointment of an environmental champion. Three basic skills were observed as being the minimum required of an environmental champion:
  - enthusiasm and inter-personal skills;
  - the ability to give guidance on ideas presented to them by understanding the motivations of the company and by taking a life-cycle view of the product;
  - the ability to act as a conduit to the correct sources of information for more involved environmental questions (*"I know a man who can..."*).

  Although this person looked slightly different from one company to the next, their basic job remained the same - to give enthusiasm and advice to the design function and to filter environmental information from corporate & external sources. (This factor was explored in greater detail in Chapter 5 as it relates directly to hypothesis 2 - awareness and enthusiasm.)

In conclusion three key aspects of environmental communication and information supply have been identified. The environmental champion is identified here as being a central source of motivation, information and training for designers. This champion holds the key skills of enthusiasm; the ability to view each product holistically; and the knowledge of where to go for the solutions to environmental problems. These skills are similar to those of the concurrent engineering champion identified by Smart [98], where education, guidance and support, and enthusiasm are cited as key skills.

The supplier network is a source of information that is largely under-utilised. It could be argued that those companies who are advanced in their approach to supplier involvement are at an advantage when environmental questions need to be raised. The expertise that suppliers have in the specific issues connected to their components and materials has been seen to be of great advantage to companies when learning about what design options are environmentally favourable. A close supplier relationship could also be argued to be advantageous when it comes to companies making demands of their suppliers for environmental reasons; the supplier would be ready for the environmental demands made by the company, enabling them to adapt their products accordingly.

The need for effective communication of environmental ideas across functional departments is important for achieving environmental improvements in products. For this the technical language used by each department had to be learned. Common training across companies and the collocation of design teams were two such ways of achieving good communication, although difficulties were often experienced when products were being developed by world-wide design teams or with design projects that extended to third party contributions (i.e. design consultancies, design contractors or external suppliers).

6.3.3. Whole-life thinking

The third category presented in the emerging framework relates to a broader corporate vision of environmental issues and how they relate to product design. This category lists two factors that describe how companies have changed their attitudes and begun to think longer term about their products and services. This rethink about what constitutes core-business for a company has been seen to allow different approaches to product development and for environmentally conscious design tools to be implemented that may previously not have been considered possible.

- **Ecology = economy.** Some companies had reached a breakthrough where they began to realise that ecological improvements to a product could actually also result in economical improvements for the company. These companies had long since left behind the perception that anything labelled 'environment' was going to be costly, in favour of the realisation that:
  "if you can establish a link between business opportunity, cost reduction, and design for environment that will drive it much further than anything else".
  Another view that was taken in this direction was that waste = cost. This attitude concurs with teachings from the total quality and total cost philosophies, and so was seen to be a good way to communicate to designers the need to cut down any potential waste in each product from the very start of its design.
- **Asset management/product stewardship.** Given the previous case, where designers had begun to understand the view that environmental improvements could be opportunities to save or make money for the business, designers were said to begin to think differently about the products they were developing. Some of the companies surveyed were now striving to retain ownership of their products and were concentrating on the service they were providing to the customer, rather than merely focusing on the physical artefact; the product was becoming an incidental part of the customer's purchase. An extreme example of such a change in philosophy would be for a washing machine manufacturer to stop selling washing machines, and instead begin to provide a washing service, where clothes were collected, washed and delivered back to the customer, so that the customer

need not worry about owning the product. (This service could be called a ... laundry service! This example was purposely chosen to highlight that there needs to be a serious re-think about exactly how to provide these services, so as to retain the level of flexibility that the customer enjoys, yet without owning the product.) A less extreme example would be if the washing machine company were to lease their product to the customer and guarantee its collection when the customer was finished with it. The advantages to a company of such an approach are that they can retain control over their assets, ensuring that at the end of its useful life a known source of equipment will return to their factory. This equipment could in turn be reused for future contracts, or for raw materials in future products. Despite the present confusion that exists about the legalities involved with asset management (i.e. according to certain laws, some materials become hazardous if they are labelled as being end-of-life, but can be freely distributed otherwise) companies from the survey were confirming their future commitment to such an approach.

In conclusion the activities that have been described here are from maturing companies who have begun to realise the business advantages of their environmental actions. By adopting similar philosophies to those of total quality management, in particular 'the cost of quality' [99], companies have developed their understanding of waste resulting in a negative cost to the company into a realisation that positive environmental action can actually result in economical advantages. Exceptions to this view do arise however, by companies who are just beginning to integrate environmentally conscious design into their operations. This viewpoint is argued by some to be weak as it uses 'possible costs of non-conformance' as an argument to tip the balance in favour of more costly environmental improvements. However the companies who do use these arguments believe such estimations to be valid. (This hints that only the richer companies can afford such speculative investment in environmental issues, possibly leaving smaller companies behind.)

Once a positive stance has been established towards environmental improvements, companies begin to alter their perception of what core business means to them. Advanced companies (i.e. those which have been practising environmentally conscious design for the longest and which are saving/making money as a result of environmentally conscious design) are beginning to reclaim ownership over the products that they once sold, and looking again towards lease arrangements with their customers (a practice that many had abandoned in past years). Whether or not such a change to core business was originally made for environmental reasons (companies often admitted the start of their asset management activities being driven by the desire to retain intellectual property and customer loyalty) the environmental advantages are recognised and often said to be the catalysts for further ventures down the asset management route.

6.3.4. Hands-on ECD

This category groups information about the actual practice of environmentally conscious design. Three factors relating to the timing of design decisions, specific design features and design tools are described in relation to environmental considerations.

- **Critical phases of design.** The timing and scheduling of environmental decisions was found to be important for their successful integration into the design process. The very early stages of the design process were seen to be those which influenced the environmental profile of the product the most, particularly in the pre-specification stage of design. (This factor was explored in greater detail in Chapter 5 as it relates directly to hypothesis 1 - timing of environmental decisions in design.)
- **Critical design features.** Designers mentioned many environmentally related product features that they were trying to incorporate into their designs. The features that were seen as being key to environmentally conscious design were wide-ranging and included: modularity; energy saving devices; snap-fits; weight reduction; dematerialisation; design for disassembly; materials identification; upgradeability; longevity; and alternative technology. This list is interesting because it includes features that could be achieved through common-sense solutions as well as through detailed techniques. (A common-sense solution could be to include simple materials identification in an obvious place on the product. A more detailed technical solution could be to introduce snap-fits into the moulds of a product's casing.) Some of the issues raised here, such as longevity or alternative technology, required a great deal of strategic insight about what the company's long-term goals were, and so were said to be difficult for designers to tackle, unless a whole-life view of the product was taken by the company. Another issue was one of standardisation. It was felt important to have whole-company guidelines about issues such as standard fittings and fastenings, so that at end-of-life/re-use all products were similar to each other, making recycling/refurbishment possible.
- **Tools and techniques.** Every company interviewed was using some form of environmentally conscious design tools or techniques, whether in the form of software, paper-based, checklists, target-plots, life-cycle assessments, workshops or handbooks. Data were not collected on the specific tools that were used in the companies, but all tools and techniques fell into the general categories of *'assess, report, prioritise'* as was detailed in Section 5.4.1.5. The types of tools used varied from one company to the next; one common factor though, was that qualitative tools were more favoured by designers due to the fact that they gave a good indication of environmental issues in a relatively short amount of time.

In conclusion the actual practice of environmentally conscious design has been described in terms of three subdivided elements. The timing of the introduction of environmental decisions into the design process has been explored. The very early stages of design are the most significant times at which to introduce environmental considerations, especially in the pre-specification stage of design. This is the stage where there are presently no tools to aid designers. Reasons for this could stem from the fact that environmentally conscious design tools originated with a focus on the disassembly and recycling of products (i.e. at the very end of the product's life, and later in the design process), or because it is very difficult to make tangible design decisions at a stage of the design process where a product concept has not been drawn up. Environmentally conscious design tools are also traditionally analytical or quantitative (calculating the amount of snap-fits required, or eco-points accrued, or different types of material in a product). Only recently have qualitative tools begun to emerge that attempt to bring reasoning and social factors into consideration. Such tools have not yet made their way into the early stages of design.

There are many tools available for environmentally conscious design. The catalogue is expanding to include tools that range from manual to IT-based; quantitative to qualitative; detailed to abridged; and expensive to free (rules of thumb). Every company in the survey spoke of using at least one environmentally conscious design tool or technique. Environmentally conscious design tools appear to be at best, the ways in which to ensure that all environmental issues of concern to the company are integrated into the product design, and at worst, a way for top management to show their environmental commitment by spending money on technology solutions. The most convincing results were seen when companies had used their tools in a systematic manner, tailoring them to their specific needs and using the environmental champion to ensure that the tools were understood and used throughout design. (This was often achieved by holding workshops for designers to practice the use of the tools on current product designs.)

Environmentally conscious design features play a large part in every company's environmental activities. Companies seem to begin their environmentally conscious design activity by 'greening' certain aspects of their products (e.g. doing a design for recycling exercise). This is similar to the process of green design, described by Dewberry and Goggin [40] as focusing on single environmental issues relating to the design of products. Having carried out one or two green design activities companies often begin to look for tools that gather many single issues into more holistic practices.

The act of hands-on environmentally conscious design was the most dynamic category observed in the companies - it was possible to gauge the relative environmentally conscious design maturity of a company by the way that they described their environmentally conscious design activities. From the author's observations, environmentally mature companies describe a more systematic approach to their environmentally conscious design activities, whereas those companies who are just beginning to consider environmentally conscious design tend to carry out single issue activities, more in line with the explanation of green design above.

6.3.5. Positioning in 'the world'

This final category lists all of the comments about where the companies saw themselves on the path to environmentally conscious design, and what problems they were encountering with environmentally conscious design integration.

- **Direction.** No company thought they had achieved environmental excellence! However, many had a good idea about how to proceed and to continuously improve their environmentally conscious design efforts. One future ideal was quoted as being to have an environmental champion positioned in each business unit of the company. (This particular company had not been practising environmentally conscious design for very long and had their environmental champion positioned at corporate level.) Many people talked of the low-hanging fruit that is ripe for the picking in environmentally conscious design - i.e. the common-sense and low-cost environmental improvements. This was also cited as being a good reason to concentrate on quick and simple environmentally conscious design tools and techniques that designers could use in a short amount of time; it was thought that detailed and complex tools would have their day in the future, when all of the common-sense improvements have been made. Most interviewees felt that their company was making good environmental progress, although all would welcome more commitment, especially from their marketing departments. Marketing were found to be at a great distance from the design process, both in the understanding of environmentally conscious design issues and in the decision-making process. Many designers spoke of their frustration in trying to make environmental design improvements, only to have them disapproved by Marketing due to concern over their saleability. Where attempts had been made to include Marketing in environmentally conscious design workshops, the response was often poor. This issue was high on many environmental champions' agendas. It was also stated that more financial backing to environmentally conscious design from top management would be a great help in every case. A few visionaries saw a future shift in their company's core business, from concentrating on the physical product to providing a service instead, and retaining their assets. Designers also recognised the benefits of investing in today's products and processes to reap the benefits later. It was widely thought that although a great deal of environmental design improvements could be made that would benefit the company, (due to innovative environmentally conscious design strategies,) there would come a time when intervention and assistance would be required from governments. Rather than merely legislate and prosecute for the products of environmentally irresponsible design it was felt that governments should look, in the future, to rewarding good environmental design and to encourage environmentally conscious design principles, through the provision of information and of infrastructures for the reuse and recycling of end-of-life products.

- **Problems.** In terms of companies' problems, many people mentioned that they were lacking an 'environmental holy grail' - a bigger picture of how they were doing; what to do next; which environmentally conscious design tools to use; which materials to use; and when to apply and so on. There was also said to be a lack of tools to aid environmental decisions early in the design process. Some companies were still finding the job of evangelising about environmental issues a very difficult task, with employees not fully understanding the true reasons and benefits behind carrying out environmentally conscious design. Other reported problems were more focused and included difficulties in complying with specific aspects of environmental law, and also materials-specific problems, such as reducing the toxicity of materials that there were no alternatives for. Some companies were also still of the opinion that to produce environmentally superior products was to produce high-cost products, but these were outweighed by the companies who managed to make environmental improvements to their products that were low/no-cost.

In conclusion the reflections of companies' on their environmentally conscious design performance and their projections to future activities are captured in this category. All companies seemed to be moving in the same direction, with which they were comfortable, but none thought that they had reached environmental excellence (perhaps a teaching from the Japanese Kaizen philosophy) where continuous improvement is a mantra which encompasses the constant renewal of goals. It is possible to note the environmentally conscious design maturity of the companies in this category too, by the way in which they describe their problems and opportunities. Newcomers to environmentally conscious design often talk of difficulties in creating enthusiasm and gaining commitment to environmentally conscious design from their design teams, whereas more mature practitioners speak often of specific technical problems related to environmentally conscious design, but realise the future opportunities of investing to find a route around these technical problems. A substantial amount of companies were talking of their future intentions to manage their assets more closely, either due to perceived legislation or to further their environmental goals. (Interestingly those companies who were now preparing for asset management were not citing intellectual property or customer loyalty as primary objectives.)

The feelings and experiences expressed by companies that are gathered in this category represent previous attempts at environmentally conscious design. The projections that are reported here into the companies' future activities represent the starting points for increased environmental activity.

6.4. A model of environmentally conscious design integration

On studying the issues presented in Figure 22's emerging framework of environmentally conscious design factors a certain amount of chronology becomes apparent. This chronology begins to represent the transition that companies make towards environmentally conscious design. It is also apparent, from studying the framework, that the factors presented are dependent on each other; some factors act upon others. It is now that the framework of factors should be considered as a whole, in an attempt to draw out from it a model of environmentally conscious design integration.

Figure 23 presents such a model of environmentally conscious design integration which embodies an element of chronology and company development. The purpose of a model is to explain clearly a more complex reality. The model presented in this thesis represents the complex organisational changes that companies go through when integrating environmental criteria into their designs, by describing a three stage process of change.

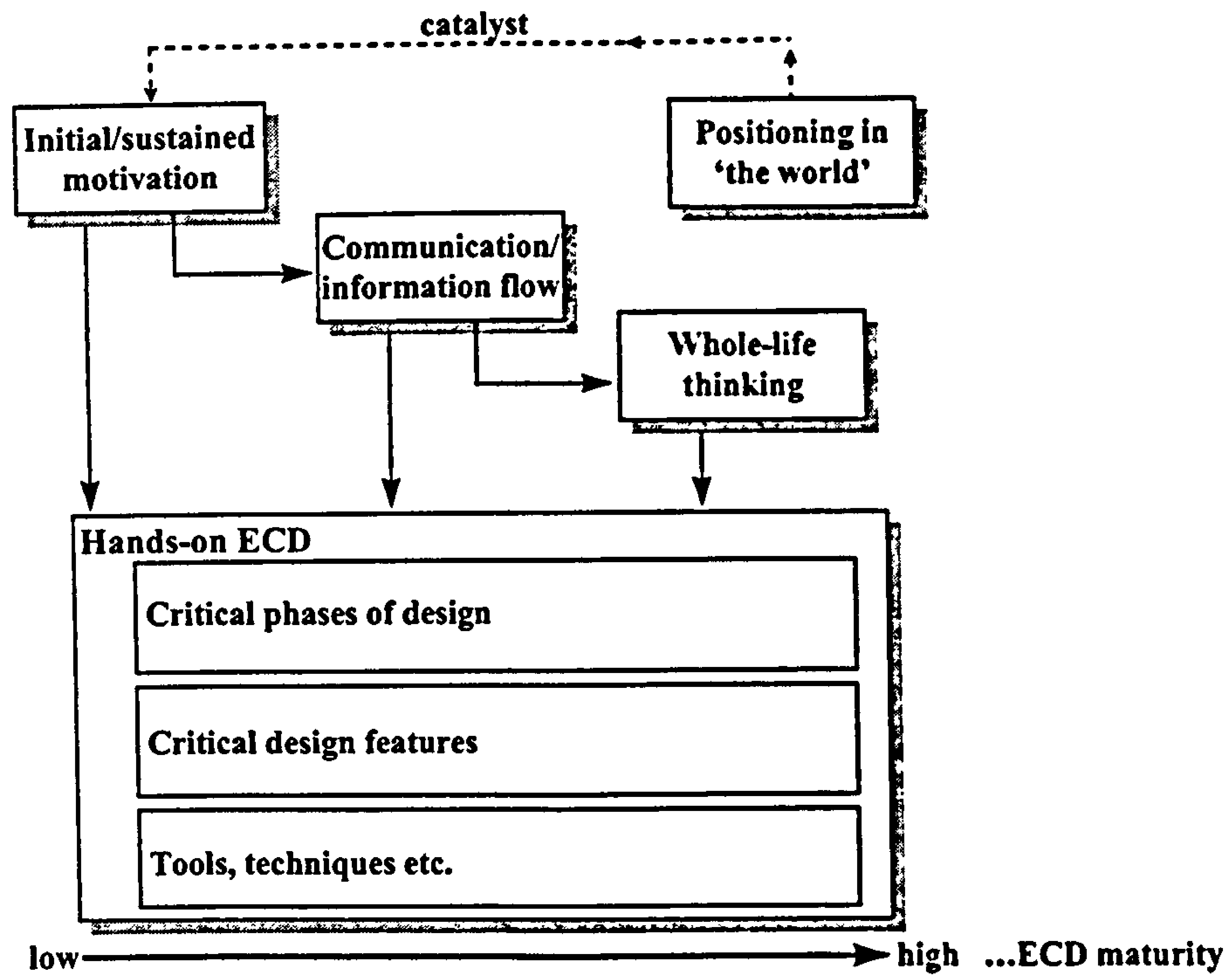

Figure 23 - A model of environmentally conscious design integration

The remainder of this section will discuss the model of environmentally conscious design integration in relation to the five categories described in Figure 23.

Considering firstly **hands-on ECD,** this category describes the physical 'doing' of environmentally conscious design. The three factors which make up this category decompose the act of practising environmentally conscious design into:

- timing - the scheduling of environmentally conscious design decisions and actions;
- product - the desired environmental features of the product; and
- tools - the tools and techniques required to achieve the features.

The last two factors are growing areas of research and there is an evolving catalogue of examples of environmental product features and of environmentally conscious design tools and techniques (as discussed in Chapter 2). The first factor emphasises the sound scheduling of environment-related design decisions. If we view down through all three factors we can see that the importance of early decisions is mirrored in the product features that can still be altered at that stage of the design process; however the availability of tools does not map to this and so suggests an area which needs further research.

Initial activity in environmentally conscious design is often catalysed by reacting to a single external demand or force, such as CFC legislation or a competitor product. This is illustrated by the category of **initial/sustained motivation** which forms the first stage of environmentally conscious design integration. Progress to sustained motivation requires significant top management commitment, unlike the initial motivation which was a reactive posture. Initial motivation may even be entirely within the design process, with little management contact. However only after top management understanding and then commitment is gained can companies consider themselves to have achieved sustained motivation.

It has been observed that when more than one of the factors in the category of initial/sustained motivation are active, some companies begin to gain momentum towards the practice of environmentally conscious design (many never leave this reactive stage). With the necessary ingredient of top management commitment it becomes possible, but not automatic, to move into the second stage of **communication/information flow.** This is characterised by increasingly wider involvement of departments into the environmentally conscious design process. For example, the need to involve marketing when proposing innovative design solutions is critical. The span of communication continues to grow and can cover design and marketing initially (in some cases) and then onto purchasing, service and transport departments. Communication takes many guises here, from the education of the workforce or membership of design reviews, via environmental workshops and training sessions; to the provision of specific information on topics such as hazardous materials, environmentally conscious design methods, and legislation updates; to the communication of company environmental goals to their suppliers; to the appointment of an environmental champion who will steer and promote many of these activities.

In this category, the company is improving its knowledge of environmentally conscious design, often by drawing upon the knowledge already available from its own personnel, and also its environmentally conscious design maturity (as is depicted by the notional **low→high** 'ECD maturity' scale at the bottom of Figure 23). This is the second stage of environmentally conscious design integration.

Again, after the company has spent some time in this second stage of environmentally conscious design integration and has increased the community acting upon environmentally conscious design, their knowledge and experience will build up sufficiently that they will move naturally into the third and final stage of environmentally conscious design integration. **Whole-life thinking** occurs in companies where the motivation towards environmentally conscious design is high and widespread. Within this stage we can observe increasing understanding of the trade-offs available between different product life-cycle phases and confidence in how to deliver it.

An initial realisation in this category is that ecological improvements can also mean economical benefits for the company. This can, for example, lead to an adjustment in the view of what constitutes core-business for the company, from focusing on product development and manufacture to service provision. It is this change in philosophy that enables the company to take the view that their products are assets which should be fostered even after they have been sold to the customer. Whole-life thinking requires high levels of **communication and information flow** between the various parts of the company and also **commitment** from much further up the management chain than any previous environmentally conscious design strategies. It can be seen from Figure 23 that the company will now have further improved its 'ECD maturity' and will have a firm environmentally conscious design strategy.

Whole-life thinking is not perfection, however. To fully realise this excellent capability a performance focus is needed which continually seeks the next benchmark or the next tool or the next product feature and incorporates them into their own goals and plans. For example, Company X seeking to remove all fire retardants; or Government Y preparing legislation for recycling; or Company Z including design management in planning for future disassembly plants. This category seems to stand out on its own. The **positioning in 'the world'** category uses external awareness and company goals and benchmarks as a constant encouragement to environmentally conscious design activity.

Figure 23 represents a relationship between the elements of a physical design process ('hands-on ECD') and the elements of a change process (the categories that describe the steps towards an improved physical design process). Although the thesis and the research questions were targeted at both the physical design process and the process of change towards environmentally conscious design, the data have emphasised the process of change as being of greater concern to practitioners.

6.5. Conclusions

This chapter took the data from the sector-wide interview survey and grouped them into a series of factors that affect environmentally conscious design. On their own, these factors made interesting studies into some of the important aspects of environmentally conscious design. When collected together, a framework was constructed which grouped the factors into five categories, integrating the wider context in which the research hypotheses lay.

For environmentally conscious design to be active in a company there must be both an initial catalyst and sustained motivation, from either within or without the organisation. Although legislation is often an initial reason for a company to begin practising environmentally conscious design the requirements of legislation can soon be surpassed. This highlights the company's desire to be self-regulating rather than to be told how to act by government. Competition from other companies also aids the continuous motivation towards environmentally conscious design. Every functional department has a role to play in ensuring that environmentally conscious design is carried out in their company. Top management provide the corporate vision and the resources; EH&S provide the control; middle management provide the environmental champions; and design provide the creativity and technical expertise.

Once a significant level of environmentally conscious design motivation is achieved it is sustained by communication with other departments. This communication is a core task of the environmental champion, who will provide awareness and training in the need for, and practices of, environmentally conscious design. The environmental champion has a further task of ensuring that all functional departments are talking the same language as each other, in order to ease the communication of environmentally conscious design ideas.

In isolated cases suppliers were found to be integrated into the communication process. These cases highlighted that suppliers are key sources of materials and component information that should be utilised to the full when specifying environmental alternatives to existing materials and components.

As companies mature in their environmentally conscious design practices it becomes possible for them to equate environmental product improvements to economic savings, due either to the cost savings of: reduced waste; reduced legal liability; increased efficiency (e.g. using less materials per product); or increased business (due to increased customer loyalty and the establishment of leasing services). This highlights a change in a company's attitude towards their products, from one of selling the product once it is manufactured and ending the relationship there, to one of seeing the product as an asset which may have multiple lives, and so extending the relationship between producer, product and customer.

The actual practice of environmentally conscious design matures as each company undergoes a transition from:

1. simply designing; to
2. gaining environmentally conscious design motivation; to
3. learning about how to develop and communicate environmentally conscious design ideas; to
4. taking a whole-life view of their products.

Companies typically start by making single issue improvements to their designs and slowly develop more sophisticated tools and techniques for including environmental criteria into their designs. From the range of tools and techniques available to designers, most prefer simple qualitative approaches that demand little of their time. Environmentally mature companies are realising that this is because environmental decisions need to be made very early in the design process, which is when little is known about the tangible aspects of a product.

Most companies are satisfied with their environmentally conscious design efforts, but all have a vision about how they should improve. There is a general trend towards taking a whole-life approach to product design, although many companies do not yet know how this will be implemented. For these and other issues companies often compare their activities with those of their competitors.

The transition from design to environmentally conscious design implies a certain amount of order to the way in which companies develop. The framework of factors affecting environmentally conscious design that was constructed at the beginning of the complex data analysis was developed, with the understanding gained from further analysis, into a model of environmentally conscious design integration. This model represents both the environmentally conscious design process and the stages of change that companies often go through when developing this process and can be used by organisations to map their own environmentally conscious design maturity and suggest directions for improvement. Three stages of environmentally conscious design integration are described which result in progressively increased environmentally conscious design performance. As the company develops through this model, their understanding and use of the environmentally conscious design tools and techniques becomes more sophisticated, and their approach to environmentally conscious design more systematic. A final element of this model shows that the vision and values of a company act to change its environmentally conscious design integration.

chapter 7
discussion

This chapter discusses the findings of the research with respect to other research in the field. The research approach is evaluated and the model of environmentally conscious design integration is discussed with respect to its use to industry and academia. The author's views of the subject of environmentally conscious design are also discussed in this section.

7.1. Discussion of research findings - an emphasis on change

At the outset of the research the view was that there was a need to explore the integration of environmentally conscious design tools and techniques into the design process of companies in the electrical/electronics industry sector. A design theory perspective was adopted to attempt to identify these changes in companies. The semi-structured interview questionnaire used in the sector-wide interview survey was designed so that three interview topics were design-oriented and two were based upon the process of change in design. Despite this emphasis on the design process, it was noticed that the data and the resulting model of environmentally conscious design integration (Figure 23) were shifting focus from the originally expected design focus to one of change as Figure 24 describes. This shift in focus was led by industry. The model shows the changing emphasis between the design process and the process of change in this research. Much of the discussion in this chapter takes the results of the research and compares them to the literature on change to add to the previous chapters' focus on design.

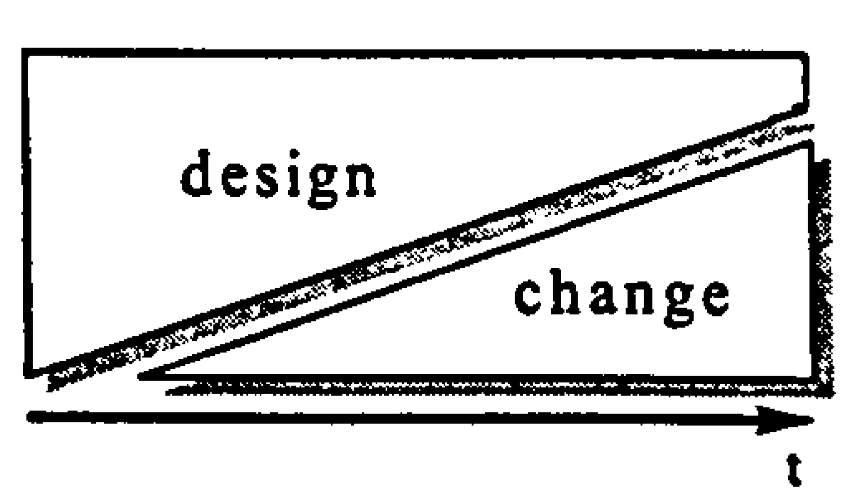

Figure 24 - Change in focus of data led by industry

7.1.1. A catalyst for environmentally conscious design

Having interviewed twenty four people from the electrical/electronics industry sector the initial reasons for companies to begin to practise environmentally conscious design became apparent through a number of media, both within and without the organisation. In terms of the external catalysts for industry to begin to consider practising environmentally conscious design, research findings concurred with the literature review (Section 2.1.2), where three main reasons were uncovered: legislation; competition; and consumer pressure. Argument et al [75] break down these catalysts for environmentally conscious design into greater detail, where they uncover the areas of: legislation; consumer demand; company strategy; competitiveness; and producer responsibility. In their study of eleven academics and nine industrialists, Argument et al arrive at an interesting response about industry's and academia's view on the need for environmentally conscious design. Figure 25 shows this response and highlights the areas of consensus and disagreement between industry and academia.

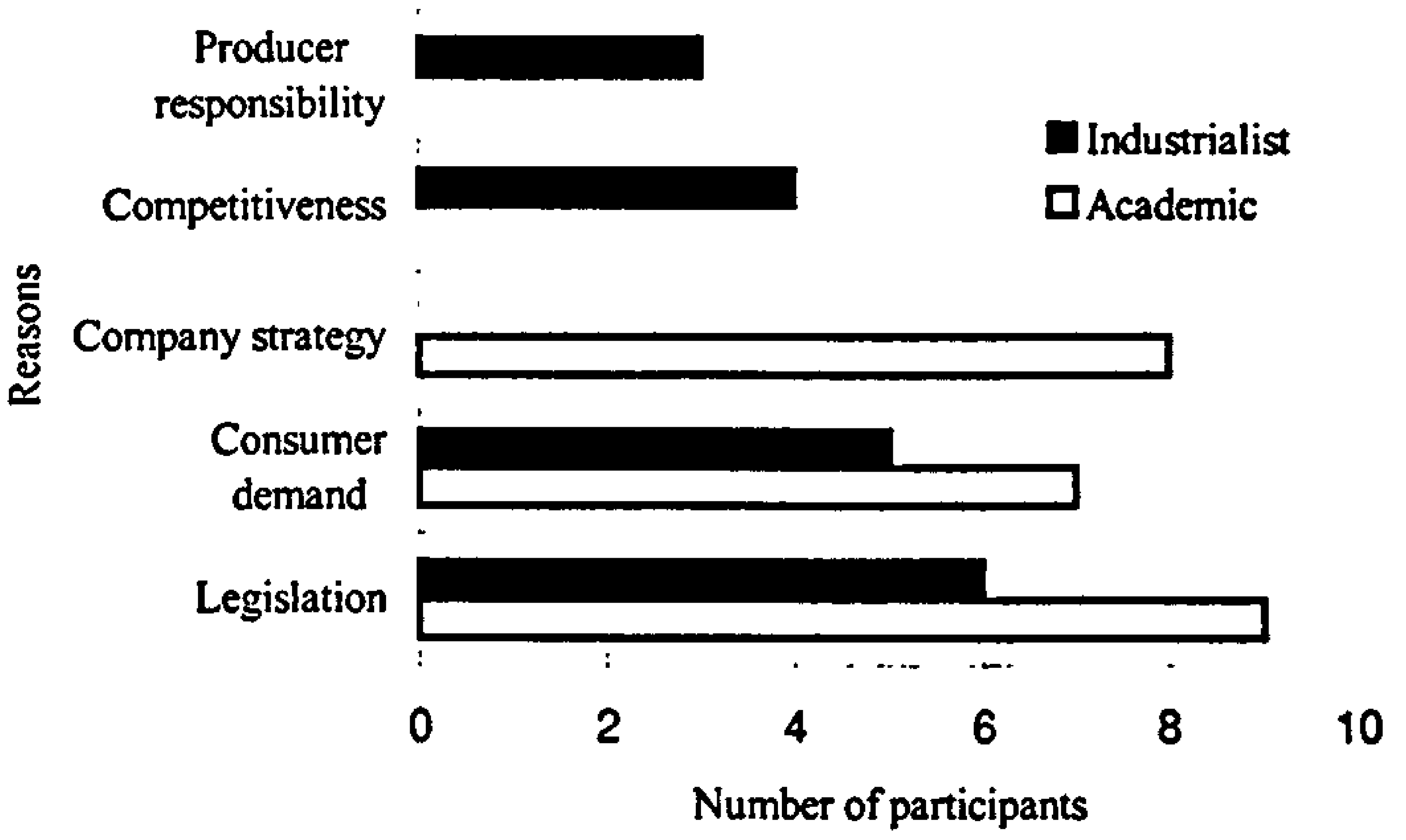

Figure 25 - Perceptions of catalysts for ECD (Argument et al [75])

In this study, both industry and academia were found to believe that legislation was the main driver for environmentally conscious design, followed by consumer demand. Thereafter, the two groups parted, with academia believing firmly in long-term company strategy as being a reason for environmentally conscious design, and industry stating competitiveness and producer responsibility as reasons. For this thesis, the author considered the issue of 'producer responsibility' to be a part of 'legislation', so this did not show up as a separate reason for carrying out environmentally conscious design. This leaves the three findings from Argument et al's industry survey: legislation, consumer demand and competitiveness that are in agreement with the findings of this research. It is interesting that the remaining issue, 'company strategy' that gained a sizeable vote from academia was not mentioned by industry as being a catalyst for environmentally conscious design. The author's feeling was that, by their very agreement to take part in the industry survey, companies were displaying a pre-existing positive change in their strategy, towards environmentally conscious design. This allowed them to be open about their achievements and their failings; it was possibly not apparent to them any longer that they had altered their long-term company strategy to reach this point.

7.1.2. Does ecology = economy?

One important finding from this research concerned the issue of balancing ecology and economy. Companies who were in the third stage of the model of environmentally conscious design integration (Figure 23) all reported to have come to a significant realisation that ecological improvements could equate directly to economical improvements. Other companies were still struggling with this thought and were less convinced about how achievable such a goal was. Stevels [100] reflects this concern and argues that to some extent environmental improvements can indeed be made economically in a product, but there comes a stage where both company and government investment is required to achieve environmental improvement. Where this opinion was the most apparent was in the electrical industry sector, rather than the electronics industry sector, highlighting a definite split in the survey sample. One possible explanation for this split is that as electronics equipment develops, new products are becoming smaller, less energy intensive and more reliable, whereas the electrical industry is presently caught up in a 'Watts war'; electrical products sell on the amount of power they consume - 'the bigger the better' is the message that consumers are being delivered. When questioned about this problem electrical product designers expressed the desire to begin to reverse the upward power-rating spiral, but could not due to the fact that their competition would not turn around with them - their marketing departments would not allow it for the same reasons. A step towards a solution would be to ensure that Marketing were brought into the design function early on and that the environmental effects of their decisions be explained. Many companies had tried this, however, but reported very little success in managing to get marketing to attend such events.

White goods manufacturers expressed further problems than just electrical power consumption. Using the washing machine again as an example, manufacturers of washing machines told of great problems, in that their product's two greatest environmental impacts were detergent and water usage during the in-service phase of the product's life. Small improvements had been made to the designs of their products, but without great investment into research or capital equipment, step environmental changes were not viable.

It is apparent then that this statement of ecology = economy holds true for some product groups and not others. It would be interesting to isolate this statement as a hypothesis for a separate piece of research into identifying product categories in terms of the environmental achievements that can be expected of each category.

It seems ironic that when looking for new and improved business solutions to ensure that ecology = economy, to get the answers we tend to be looking to the past. The example of the washing machine in Chapter 6 (Section 6.3.3) explained the idea of washing machine manufacturers either providing a laundry service, or leasing machines to their customers. These two business activities combine to form a significant part of washing machine manufacturers' history. Perhaps then, there is a lesson to be learned, that with some care and adjustment old business philosophies may be re-workable in modern society, and thus affect the way in which goods are designed.

7.1.3. Sustainable design: are designers lost in terminology?

Section 2.3.5.1 discusses two of the many definitions for sustainability and comments that these definitions are so wide-reaching that they are of little help to designers when trying to understand how to practice sustainable design, as is often their remit. Van Someren makes the observation that the concept of sustainable development is almost exclusively a discussion between academics, due to: *"the far-reaching consequences of all the necessary changes which have to be implemented,"* and because *"the discussion on sustainability focuses on macroeconomics rather than business economics, and most of the contributions of the latter category are descriptive"* [101]. Comments were made informally by designers about the problem of understanding exactly where they stood in the link to sustainable design. The focus group established by the author during this research, *eco2* [20], made an attempt in **Figure 8** to relate the various environmentally conscious design philosophies and terms together, so that designers could understand what affect they were having on sustainability if they were carrying out, say, design for disassembly.

7.1.4. The need for an innovative company strategy

The model of environmentally conscious design integration (Figure 23) shows three organisational stages that companies travel through when integrating environmentally conscious design. These three stages are motivation, communication and whole-life thinking. In his study of companies' levels of ecological management, van Someren [101] provides three categories similar to those presented in Figure 23:

*"In each stage a higher level of ecological management is achieved. The successive stages can be described as **defensive, offensive and innovative.**"* (van Someren [101])

Although he talks in company management terms it is possible to see the parallels between the environmentally conscious design integration stages presented in this thesis and van Someren's ecological management stages as he describes them:

- **defensive** - in this stage ecological management is said to be ad hoc and not regarded as an important issue in the company's strategy. Best case would mean compliance to environmental legislation. Environmental issues are seen to be an external problem.
- **offensive** - this stage is described as being where environmental themes are becoming more integrated into the business practice, through the collection and distribution of environmental knowledge in the organisation. Due to this increased awareness environmental protection is said to gain more attention, but cost considerations still override environmental considerations.
- **innovative** - this stage is where environmental issues become a part of the company's strategy, and where ecological improvements are equated to economical improvements in the company. By taking a whole-life view, companies begin to view their products as assets and so look to selling a service, rather than parting with their assets.

Having identified these three stages in companies' development of ecological management, van Someren does recognise that it is not always quite so cut and dry, and that several characteristics from each stage may be in evidence at any one time. This was also observed throughout this research; however a model can never hope to represent each individual case, rather a general picture of what has been discovered. Of the need for innovation to achieve sustainability, van Someren goes on to discuss the way in which ecological issues should be equated to economical principles wherever possible:

"Because of the accumulation of knowledge, compliance can contribute to acquire a competitive advantage in the long-term, thereby creating a surplus value. The value conversion principle can be applied when striving for an integration between economy and ecology." (van Someren [101])

This hints at the ability to see any ecological improvements as economical benefits, if one would only look into the longer-term. Perhaps where companies are presently becoming stuck is at the point where significant environmental improvements (such as in the previous example of washing machines) would be economically prohibitive. A different view would weigh the economical costs of not conforming to environmental improvements by including possible clean-up and prosecution costs of non-conformance in the longer-term. This is a recognised dilemma, and companies can only think as long-term as they can afford, hence Stevels' [100] view of the necessity for government intervention to enable certain environmental improvements.

Relating this fixing of environmental ideas into a company's strategy to the general body of change management philosophies, Kotter [102] confirms that companies have to go through a series of stages before reaching their strategic level and highest performance, and that there are no short-cuts if the final strategy is to be a solid and successful one:

"The most general lesson to be learned from the most successful cases is that the change process goes through a series of phases that, in total, usually require a considerable length of time. Skipping steps creates only the illusion of speed and never produces a satisfying result." (Kotter [102])

The stages of environmentally conscious design integration that the model describes (Figure 23) can be thought of as such phases; the warning that each phase must be experienced in turn, is an important lesson for companies, if they hope to achieve a solid environmentally conscious design strategy. Kotter goes on to describe eight phases that he sees companies going through on the road to change:

1.	establishing a sense of urgency;
2.	forming a powerful guiding coalition;
3.	creating a vision;
4.	communicating the vision;
5.	empowering others to act on the vision;
6.	planning for and creating short-term wins;
7.	consolidating improvements and producing still more change;
8.	institutionalising new approaches.

Table 11 - Kotter's eight phases of organisational change

Again, parallels can be drawn between these phases and the model of environmentally conscious design integration, as Table 12 illustrates.

Model of ECD integration	Kotter's eight phases of organisational change
Positioning in the world	1. establishing a sense of urgency;
Initial/sustained motivation	2. forming a powerful guiding coalition; 3. creating a vision;
Communication/information flow	4. communicating the vision; 5. empowering others to act on the vision; 6. planning for and creating short-term wins;
Whole-life thinking	7. consolidating improvements and producing still more change; 8. institutionalising new approaches.

Table 12 - Relationship between model of ECD integration and Kotter's model

In terms of the companies who actually have an innovative environmental strategy in place, Smith et al [35] confirm that these have gained business advantage through innovating and differentiating their products, by presenting them in an environmentally positive light. They also go on to say, however, that the number of companies who possess such a strategy are still very few, and are often confined to niche market sectors. They too hypothesise that for the widespread adoption of environmental strategies, some form of government intervention will be required.

7.1.5. Making a change happen

The environmental champion was found in this survey to be key to the integration of environmentally conscious design. The champion's role was often said to be of an enthusiastic and charismatic person, who could answer most environmental questions, or at least would know where to look for the answers to more involved environmental queries. Communication skills were also rated as important requirements for environmental champions, particularly with respect to being able to communicate with the engineering and design functions. Lenox and Ehrenfeld [69] echo another finding related to environmental champions, that of the role that they have in bridging the gap between the corporate and business levels of the company, where they act as conduits for information exchange in both directions:

"Case studies indicate that environmental design capabilities may be greatest in firms which build a variety of support functions on the corporate level while co-ordinating them with product development teams through training and extensive use of environmental design champions." (Lenox and Ehrenfeld [69])

They go on to confirm that the effective application of emerging individual expertise in environmentally conscious design is more common and, they argue, more successful than the development of complex environmental design tools.

Referring again to Kotter [102], it is argued that any sort of change needs to be given a sense of urgency in order to initiate it. The first of Kotter's *'eight steps to transforming your organisation'* states that most successful efforts begin when some individuals or groups begin to look very closely at a certain issue of importance, and subsequently seek dramatic ways in which to report the need to resolve the issue, with respect to either the opportunities or the threats that this issue may pose. The importance of the successful implementation of this first phase of change is stressed, *"well over 50% of the companies I have watched fail in this first phase,"* and Kotter also states that the company will stay in this first phase of change until enough leaders have bought-in to the need for change. Thereafter, their job turns to one of communication and the establishment of a vision.

Shelton [103] gives four points to consider when organising for environmentally conscious design:

- *"DFE should be organised as a business management issue supported by the EH&S functions;*
- *DFE should produce more competitive products - not green products - and be owned by the product management team in each business unit;*
- *DFE programmes should start small, expand incrementally;*
- *management must recognise that development, integration, and growth of DFE organisations will almost certainly be uneven across the company."* (Shelton [103])

This echoes Kotter's view and this thesis in that environmentally conscious design should be made into a business issue to ensure its successful integration, and that change must happen incrementally and steadily.

7.1.6. Attitudes to ECD tools and techniques

This research did not undertake to review nor categorise environmentally conscious design tools and techniques, but it was important for the author to have a current understanding of what exists when talking to companies. The detailed reviewing of current and emerging environmentally conscious design tools is a long and involved task. Sweatman and Simon [41] have carried out such a review and present a classification of the different types of tools and techniques available. Their first classification of environmentally conscious design tools is into analysis tools and improvement tools, where:

- analysis tools are those which assess the life-cycle environmental impact of a product; and
- improvement tools are those which are for use by designers when reducing the environmental output of their products.

Applying this classification to the industry survey it is interesting to note that improvement tools are those which were more favoured by designers and environmental champions. Analysis tools were found to be too cumbersome on the whole for use in the design process, with many hours' work required to gather and input the necessary data, let alone to interpret the results.

Many existing analysis techniques raise the dilemma of usability versus validity. That is to say, when carrying out an LCA on a product, the more detail that is uncovered in the data collection and analysis, the more accurate and valid the LCA results will be. However, it has already been discussed that designers have very little time to devote to detailed LCA's and so would look for a more timely solution. The dilemma that many companies face is in establishing the cut-off point between time spent and meaningfulness of results. Some companies choose to solve this dilemma by opting not to carry out detailed analysis at all.

The abridged LCA methods that are beginning to emerge may change this attitude, however. Abridged LCA's are starting to be used by designers to gain a quick and simple analysis of a product so that environmental design priorities can be made. This fact in itself is interesting, because it means that by using abridged LCA tools, designers are beginning to do tasks that are strictly outside of the everyday design process. Some of the data collection that is required, even for an abridged LCA, is time consuming, but is obviously felt to be of worth to those designers who are increasingly using the technique.

Looking now to improvement tools, many designers in the industry survey discussed their use of environmentally conscious design tools that fitted into this category. As Sweatman and Simon [41] state, due to the many environmental issues that arise throughout the design process, there is now a variety of improvement tools available to the designer. Perhaps it is for this reason that they are so popular, because they are designed to tackle small and tangible aspects of environmentally conscious design, rather than attempt to assess the product as a whole. Some of the issues that these tools tackle are mentioned throughout Section 2.3.

Sweatman and Simon classify environmentally conscious design tools in terms of their category and of their usability in design, giving guidance about which types to use, depending on the user's requirements, as shown in Figure 26.

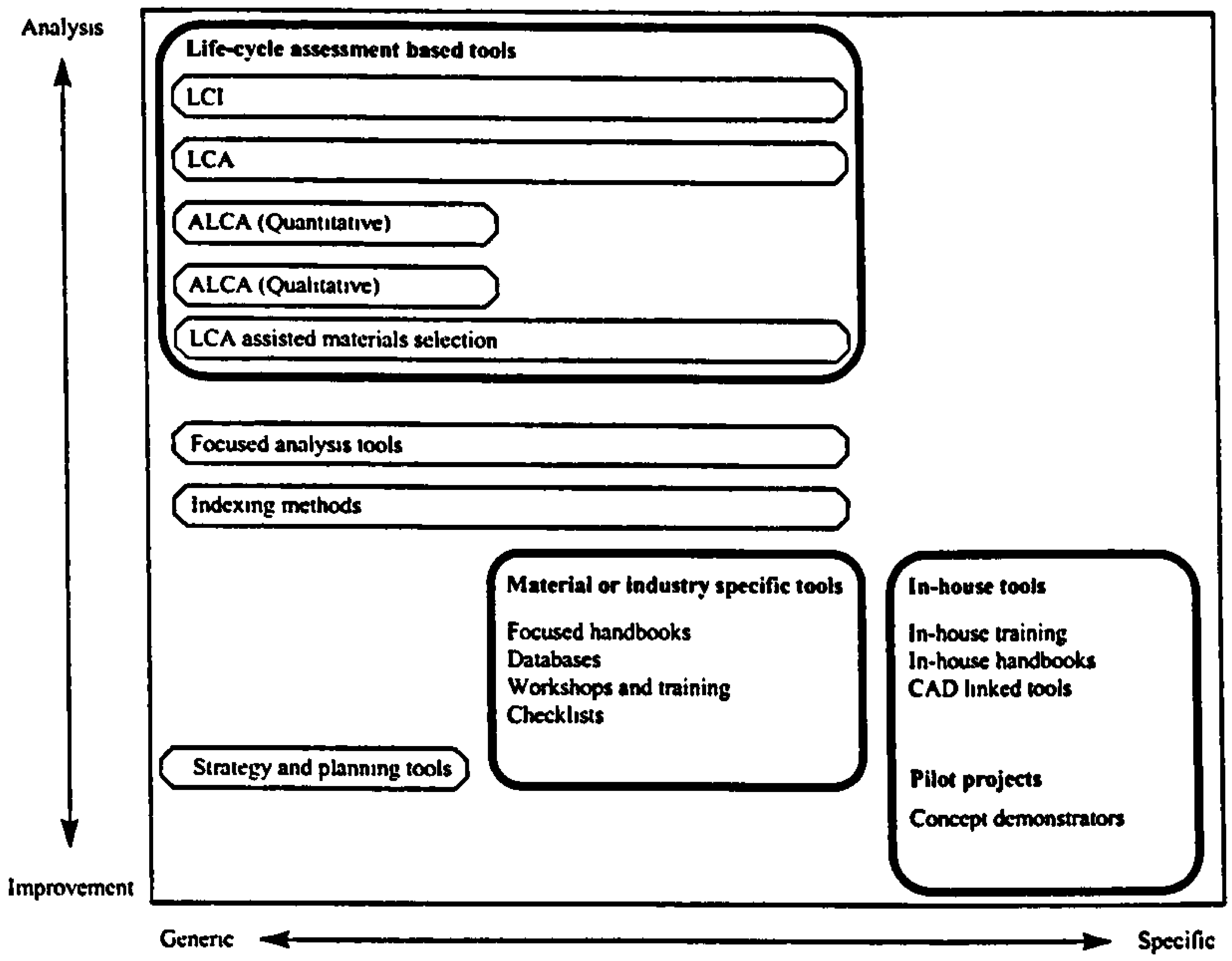

Figure 26 - Classification of ECD tools (Sweatman and Simon [41])

It is interesting to use this classification to see where industry presently are in environmentally conscious design integration. The companies interviewed for this research seemed to follow a pattern in the tools they used, depending on their level of environmentally conscious design integration. This pattern followed a general direction from the bottom right of Figure 26 (in-house tools), to top left (LCA based tools) and ending at bottom left with company strategy.

Looking in terms of the design cycle, all of the tools represented in Figure 26 are presently designed for use after the product specification has been written. This highlights a gap, where industry was reported in the survey to be lacking environmentally conscious design help in the pre-specification stages of design.

7.1.7. Future directions

Many of the organisations from the survey understood that they were on a long journey towards environmentally conscious design, but that there was a need to integrate environmental principles into design in a steady manner. For this reason many were pleased with their progress. There was also a feeling that for the next few years at least, there will be plenty of environmental improvements that are quick and simple to incorporate into design, and that designers needn't worry yet about detailed analytical design tools. This is not to say that detailed analysis techniques were thought to be useless; the ideal seen by many was to have detailed environmental analysis data available in a shorter expenditure of designers' time. Argument et al [75] reflect this desire in their survey, where the answer to their question, *"What would you spend £250,000 of research money on?"* was unanimous agreement on the establishment and refinement of good environmental databases and analysis techniques.

A widespread desire from industry was to have an increase in the amount of environmental champions in the product development process. This was due to the fact that environmental champions were seen as being an essential way in which to ensure environmentally conscious design, and also due to many companies' plans to increase their environmentally conscious design activity into the future. Many companies intended to place an environmental champion in each business unit, relating perhaps to the fact that most environmental champions were found to be educated engineers, rather than environmentalists; specific product knowledge appeared to be key so that the champion could help to steer product design innovations around areas of environmental concern, rather than to find environmental solutions to existing product design decisions.

The companies who had reached the 'whole-life thinking' stage of environmentally conscious design integration had either started to shift, or had already made a shift in their perceptions of what was their core business. Whereas in the past they had been manufacturers of products, they were now beginning to see themselves as the providers of services. The advantage for a company of this change in perception is that a new outlook on who owns the products throughout their life-time and at end-of-life enables the company to see an economic advantage in retaining their products as long as possible and for as many lifetimes as they can, whilst still pleasing the customer with the service that they are providing. This results in lower materials and manufacturing costs (through refurbish, reuse and recycling); greater customer loyalty (through the strengthened relationship in a lease arrangement); and lower risk of future product liability legislation affecting them. The advantages for the environment of this attitude are obvious: products are used for longer and will therefore stay away from landfill for much longer; manufacturers learn to make the most of their products and materials; and the attitude of the consumer is slowly changed from one of material ownership to one of the flexibility of having a service available. Dewberry [70] recognises that presently only a few companies have actually embraced such a philosophy and comments on the difficulty of getting to this stage:

"Such initiatives are rare. This is primarily due to reactions to 'change' (i.e. changing from a business as usual approach) and concerns regarding 'risk', which are both cost and image based. The concepts of change and risk are central to re-evaluating design towards a complete life-cycle awareness. This involves strategic management input, longer-term business goals, transparency of information and increased levels of communication within the company and between those involved in the supply chain." (Dewberry [70])

This is Kotter's eighth phase of change and, as he and Dewberry agree, may result in increased costs in the short-term. However the companies that arrive at this eighth phase of change have done so due to their focus on long-term competitiveness and so may justify the short-term costs.

To some degree there was agreement from the survey that government intervention will be required to ensure that sustained environmental improvements are achieved. This becomes more so, perhaps, the further one travels from single-issue environmental improvements towards the goal of sustainable design, addressing the affects of a product on society, culture, employment, economy and so forth. Dewberry makes the comment:

"It is therefore extremely difficult, if not impossible, for designers to practice a 'sustainable' design approach within the current commercial system. The concept of

sustainability relies on both top-down (e.g. government policy agreements) and bottom-up (e.g. Local Agenda 21 action) initiatives." (Dewberry [70])

This goes one stage beyond the model of environmentally conscious design integration as it begins to consider the societal and cultural requirements of sustainable design.

7.2. Uses of the model

The model of environmentally conscious design integration derived in Chapter 6 (Figure 23) describes the stages that companies in the electrical/electronics industry go through when integrating environmentally conscious design into their product development process.

As an aid to **academia** the model serves as a starting point to find out more about each stage of environmentally conscious design integration. It uncovers some important areas where there is a need for research to help design management to organise their product development process for the inclusion of environmental considerations, and to help designers to consider environmental issues at specific stages of the design process. The model provides a structured approach to incorporating environmental considerations into the design process, which is not evident in the literature.

As an aid to **industry** the model should help companies by firstly reminding them that they are not alone in their environmental efforts. Companies should be able to identify where they are in their transition towards environmentally conscious design integration, by positioning themselves onto the model. Once they have positioned themselves, companies can see what they have achieved and what they might do next in their environmentally conscious design integration programme. Although based on the electrical/electronics industry sector, the model should be transferable to other industries that manufacture products, in so far as it is an organisational change model; findings reported and represented in the model are and than sector-specific.

7.2.1. Limitations of the model

A recognised weakness of the model is that, taken literally, the scale of 'ECD performance' could give the impression that the answer to perfect environmentally conscious design is in completing all three stages and incorporating all manner of environmentally conscious design features at the right time, using all possible tools available. This is not the case. The idea of the notional scale is to give the reader an impression of progression and continuous improvement. Another important consideration here is that this model sets out to display the steps towards good environmentally conscious design practice, which is not necessarily the same as good sustainable design practice. If a company were to assess itself on the model and be certain that they were at the top of the 'ECD performance' scale throughout their entire organisation, this does not mean that they should be content, rather that they should be leading the way to finding out how to practice sustainable design.

chapter 8

summary and conclusions

This chapter presents the research findings, demonstrates that all of the research questions and hypotheses were addressed and discusses the contribution to knowledge of the research. Finally, recommendations are made for work that would further the research presented in this thesis.

8.1. Research conclusions

Most existing models and methods for environmentally conscious design are an extension of models and methods developed for other purposes (namely design itself). This thesis accepted the challenge of creating a model which can cope with the many unusual characteristics of environmentally conscious design.

By conducting an in-depth literature review, a detailed case study and a sector-wide survey of designers and design management, the objectives of the research have been satisfied. The issues facing the electrical/electronics industry, when attempting to integrate environmentally conscious design into their product development processes, have been identified and investigated. The qualitative approach to this investigation has resulted in the construction of a model which explains environmentally conscious design and describes the transition that electrical/electronics companies go through from design to environmentally conscious design.

The research deliverables have been met. The primary data from the survey and the secondary data from the literature review and the pilot study have combined to describe the lessons learned by the electrical/electronics industry whilst attempting to integrate environmentally conscious design into their product development processes. An organisational model has been constructed which puts into context the sequence and timing of actions and commitments that should be made when integrating environmental considerations into design, and which gives an understanding of the path taken by the electrical/electronics industry when integrating environmental considerations into design.

The timing of environmental decisions in design was confirmed to be key to environmentally conscious design. It was found that the environmental profile of a product is affected the most in the very early stages of the design process, particularly in the pre-specification stage. However this stage of design was found to distinctly lack tools to aid the consideration of environmental issues. The product design specification was seen to be an important place in which to input environmental ideas very early on.

The design process relies on the input of many different functional departments within a company, the tasks and responsibilities of which all have an impact on different stages of the design process. Due to this diversity of skills and to the time constraints placed upon the design team, detailed and technical environmental analysis tools were not favoured. Instead, qualitative tools that were quick and simple to use were discovered to be popular among designers, who were keen to make some environmental changes in the short amount of time they had available. The environmental decision-making techniques that were observed in industry can be grouped into three broad categories of *'assess, report, prioritise'*. *Assess*ment techniques take existing products as examples and use these to learn about the environmental goods and bads of their existing design process. A *report* is often produced to communicate the results of such assessments and also to give advice about how to include new techniques to improve the product's environmental profile. The *prioritis*ing technique takes any list of suggested design improvements and orders it in terms of environmental priority, customer priority and company priority.

An enthusiastic approach and driving force was shown to be key to implementing environmentally conscious design. The appointment of an environmental champion was a common action in those companies wanting to integrate environmental considerations into their designs. Depending on the philosophy of the company the environmental champion was found to be either very close to the design function, giving everyday contact to the design team; or at corporate level, acting as advisor and corporate environmental standard-setter. Due to the level of responsibility held and respect demanded of the job, middle management appeared to be the minimum requirement for an environmental champion, with a concern that anything above middle management was felt to become too far away from the design team to ensure a relaxed working relationship. It was observed that if environmental issues were presented in an innovative and simple to understand manner, many designers saw environmental issues as a worthwhile investment of their time. A good environmental champion who can come up with innovative solutions will therefore enjoy enthusiasm from the design team. Interestingly most champions were found to have no environment-related qualifications, nor were they expected to know the answer to every toxicological question that arose. Instead environmental champions were expected to have the knowledge of where to go to find the answer for more complex queries. All of the environmental champions interviewed actually came from engineering, and quite often engineering design backgrounds, pointing perhaps to the need for the environmental champion to have empathy with the daily routine of the people they wanted to use to bring about change.

Top management commitment was seen as being important to the initiation of environmentally conscious design in a company. Top management commitment was said to ensure the allowance of time and resources for employees to attend training courses, to appoint environmental champions and to devise company environmental goals and visions. Companies do exist, however, where environmental improvements were said to have been made due via an enthusiastic bottom-up approach. However, it was admitted that eventually some form of recognition has to come from top management, especially when regulatory and capital issues arise. Some companies felt that top management were required to constantly lead and promote environmental issues, but others believed that once a framework had been set in place, individual business groups, design teams and enthusiasts would ensure sustained effort towards environmentally conscious design.

The author has found there is a sequence of events and experiences that companies go through in the electrical/electronics industry sector when they are integrating environmentally conscious design into their product development processes. This sequence starts with some form of initial motivation to environmentally conscious design, be it from within or without the company. At this stage environmentally conscious design may be operating in the company, but only at a minimum level. When there is sufficient motivation, the company move to the next stage in the sequence, into the phase of communication and information sharing. It is in this stage where training programmes are established, environmental champions are appointed and suppliers/customers notified of the company's environmental efforts. Successful communication in this stage will ensure the further commitment from other parts of the company, and environmental goals and visions become more crystallised. The environmentally conscious design performance of the company is undergoing improvement in this stage and isolated environmental efforts begin to become more universally practised due to the publicity that they receive within the organisation, and due to the environmentally conscious design techniques that are learned as part of the company's emerging training programme. The next stage in the sequence is when the company begins to realise that there is indeed long term economic benefit to be gained from thinking about long term ecological issues. The very advanced company now begins to look towards reducing the amount of physical product that they are releasing to their customers and focuses more on the service issue. Furthermore, if they can regain their products when the customer is finished with them, this is of benefit to the company too; this is when the company has embraced the philosophy of asset management. This final stage has a profound effect on the way that designers view the products they are designing, and encourages them to take a whole-life view of their product designs. The sequence of events described here is embodied in the model presented in this thesis and allows the reader to notionally chart the progress that a company makes from simply designing, to designing with the environment in mind.

8.2. Contribution to knowledge

The academic contribution to knowledge of the research presented in this thesis has been to provide an understanding of environmentally conscious design integration in the electrical/electronics industry. A literature review has been presented which demonstrates state-of-the-art in environmental design practice and theory, with particular emphasis on the electrical/electronics industry. The literature review highlights the need for a systematic approach to environmentally conscious design so that industry may be guided when integrating environmental principles into their design processes. A transatlantic sector-wide survey has been carried out which collected the opinions and experiences of designers and design management in the electrical/electronics industry, when attempting to integrate environmental considerations into the design process. This unique survey has allowed an understanding to be built of the way in which the electrical/electronics industry sector is currently tackling the issue of environmentally conscious design integration. From this data key factors have been formed and a model of environmentally conscious design integration built. This model presents a structured approach that industry could follow when integrating environmental considerations into their design processes.

Industry has also benefited from this research. The data from the sector-wide survey have been developed into a report which can give companies confidence in their strategic environmental decisions, by providing examples of how the rest of the industry is carrying out environmentally conscious design. The model is being further developed by the DEEDS project into a self-assessment technique for companies to gauge where they are in the transition from design to environmentally conscious design. Industry has also benefited from workshops and presentations that have been delivered throughout the course of the research, which have conveyed the experiences gained from the sector-wide survey.

8.3. Recommendations for further research

The essence of this research has been to understand and present a model of environmentally conscious design integration for the electrical/electronics industry. The model presented in this thesis allows for an understanding to be gained of how one industry sector has been tackling the integration of environmentally conscious design into their product development processes. There are a number of possibilities for further research that would be beneficial. Firstly, it is believed that the lessons learned from this research could be applied to industry sectors other than the electrical/electronics industry. The results of the research presented in this thesis could be used as a starting point for research into other industry sectors, so as to build a more holistic overview of environmentally conscious design integration. Similarities across industry sectors could be embodied into a model and differences kept as a catalogue specific to each industry sector.

As mentioned in Chapter 5, the survey sample chosen for this research excluded small to medium sized enterprises. Although little exists in literature that reports the environmental achievements of small to medium enterprises, an interesting research project would be to trace the amount of environmentally conscious design activity that exists in these companies, possibly as a result of the greening of larger organisations. Smaller companies would certainly benefit from research about the environmental activities of larger organisations, so as to prepare them for the demands that will inevitably be passed down the supply chain to them.

Another area for further research would be to continue the development of the model into a tool that is useable by industry. The provision of an environmental road-map would help companies to assess what their achievements have been to date, where they are at present and what they should do next to continue their environmentally conscious design integration. A simplified version of such a tool is being prepared for the DEEDS project, which will help companies to assess themselves by means of a few simple questions. The model contains a great deal of rich data collected from industry. If this data could be made more readily accessible to companies by means of a query-based computer tool, industry could use the tool to get examples and lessons about how to carry out environmentally conscious design.

The research was conducted across Western Europe and the USA, in order to gain a representative spread of opinion and experience from the electrical/electronics industry in the Western world. All data collected were treated equally so that a general picture could be formed of the industry's efforts and achievements in environmentally conscious design integration. Another approach to analysing this data could be to break down the interview sample into individual countries, thus building a picture of the differences in environmentally conscious design integration between all of the countries analysed. This approach would require a larger survey sample than considered for this thesis.

This research chose to follow and explore three hypotheses based around: the timing of environmentally conscious design decisions and tools; the level of top management commitment required for environmentally conscious design; and the level of enthusiasm required to sustain environmentally conscious design in an organisation. There were many other interesting findings from the pilot study that the author could have chosen to explore but did not, due to time constraints. Research into these other possible hypotheses includes:

- the success of an environmental design decision is dependent on who makes it;
- the success of an environmental design decision is dependent on a team-based approach to the decision;
- environmentally conscious design is more successful in a company if the company's environmental goals are communicated to the design team;
- a different approach to environmentally conscious design must be adopted if the design team is not collocated;
- qualitative environmentally conscious design tools are more effective than quantitative;
- a company's marketing strategy dictates the upper level of environmentally conscious design improvements that can be made to a product and therefore the element of freedom that is given to designers;
- very few people read handbooks - research is required to find innovative ways of presenting and re-presenting environmentally conscious design principles to the designer;
- a common currency is required to enable designers to equate different environmental loads in their decision-making process;
- environmentally conscious design boosts creativity in designers.

Finally, one resounding conclusion from the research was that there is a need for environmentally conscious design tools to be developed that concentrate on the pre-specification stage of design. It was found that the most environmentally important stage of the design process was the stage before the product design specification is written. However, no tools presently exist to aid this area of decision-making. Any tools developed for this stage of the design process would have to be quick and simple to use and should be designed to be used by design management, not designers.

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Appendices

appendix 1

NUD•IST data

NUD•IST stands for Non-numerical Unstructured Data Indexing Searching and Theorising. It is used for the analysis of extensive textual or other non-numerical data including: conversational interviews; focus group transcripts; and historical documents, which until recent years, has been carried out manually.

The Microsoft Windows-based environment allows the qualitative data analyst to import and index qualitative data in terms of the subject(s) each piece of data addresses. By observing the emergence of a tree structure, the qualitative data analyst can build a theory around the subject they are researching, and subsequently re-index data to further explore and refine the theory. Figure 1 shows the NUD•IST environment, with the:

- Project Information List (showing the status of the current project);
- Document file (an interview transcript in the midst of being indexed) and attached indexing menu;
- Tree Display (showing the emerging structure of the theory).

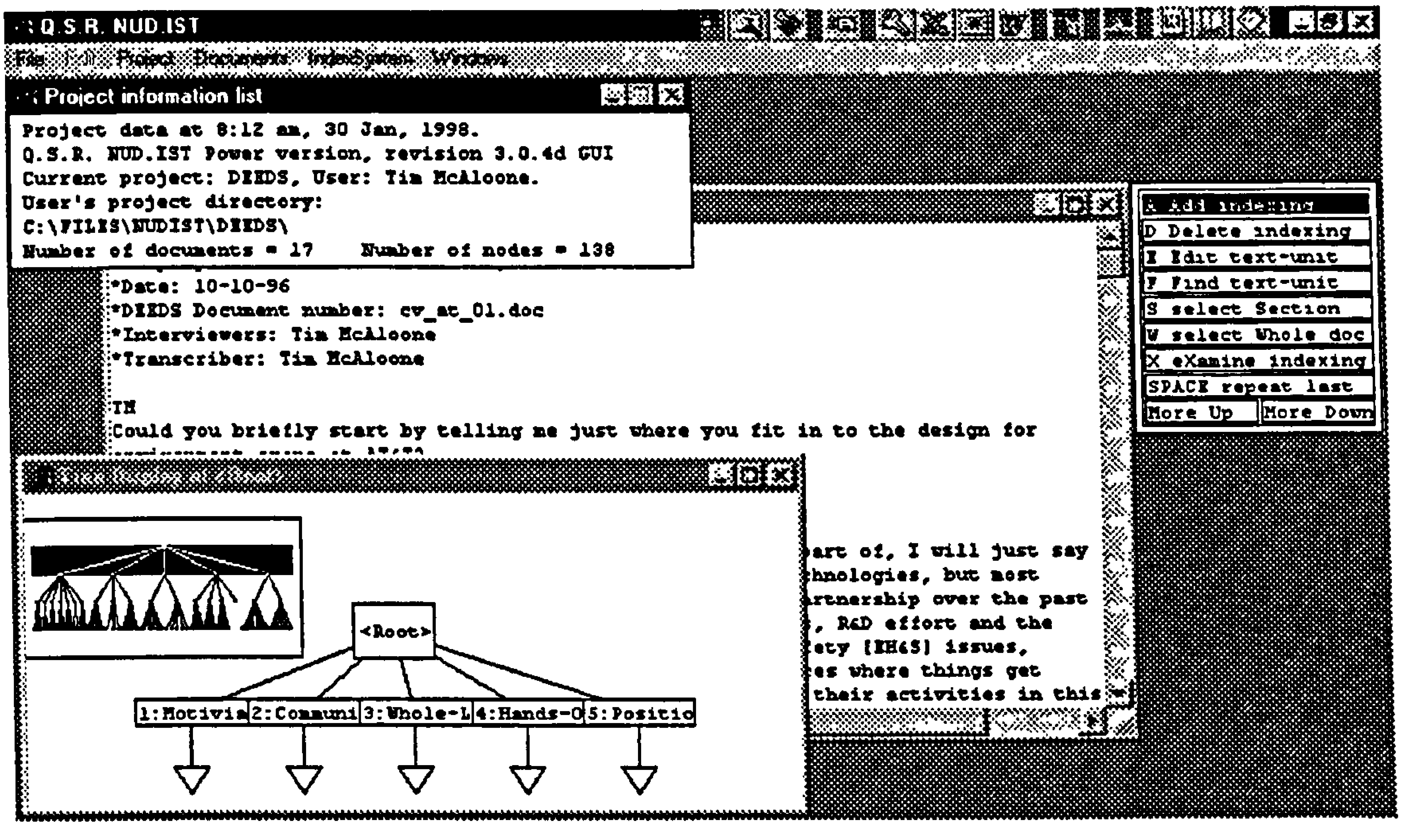


Figure 1 - The NUD•IST environment

The tree display in Figure 1 shows the various paths that are being formed in the indexing and analysis of the data; each path intersection is called a 'node'. Each node carries a numerical address (e.g. '1 4 1')which becomes its identifier. The black highlighted area in the small tree in Figure 1indicates the part of the tree structure that is presently being displayed.

Figure 2 describes how data is indexed. By highlighting blocks of text (words, lines, or paragraphs) the data analyst can add an index to the text selection, which will represent its relevance to a particular issue or issues.

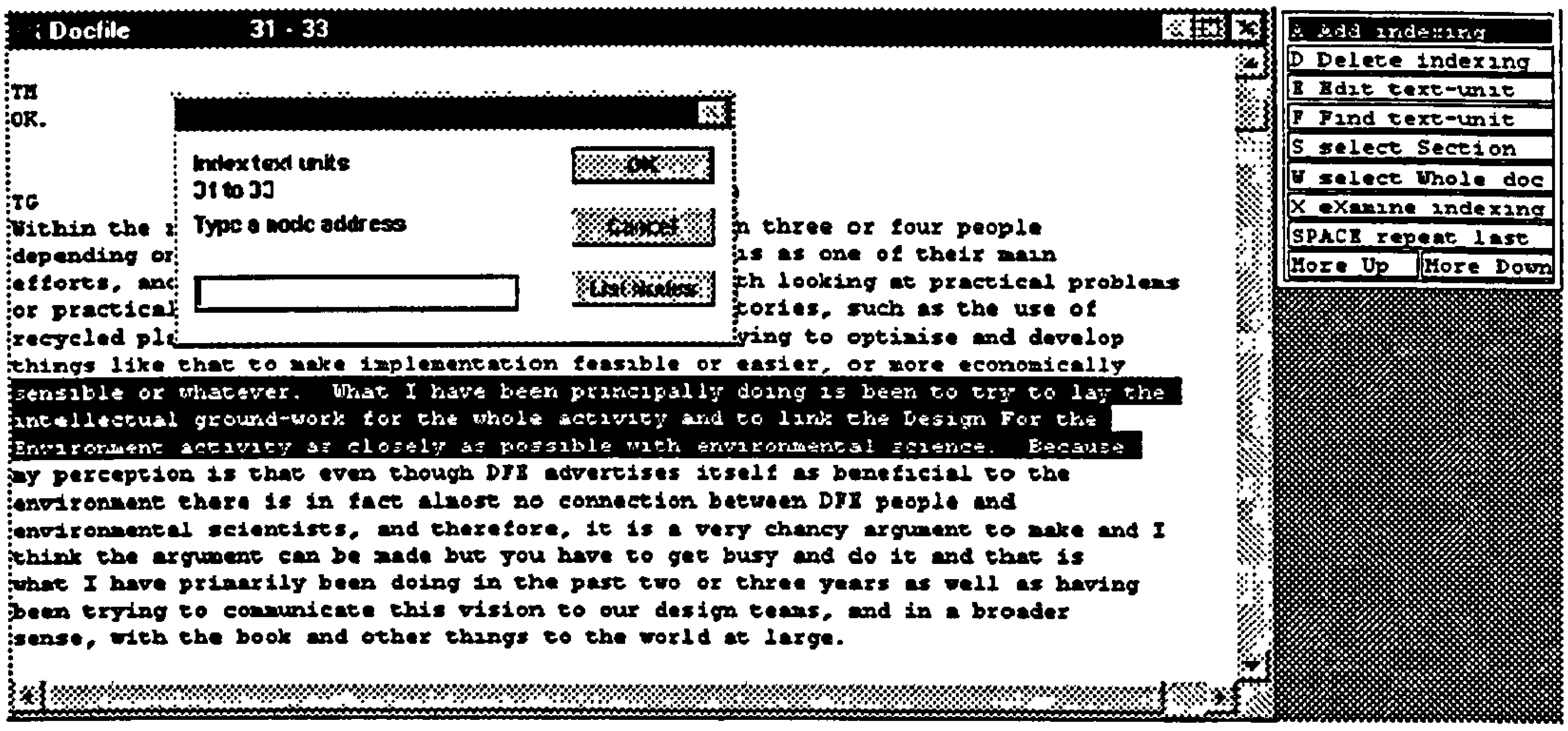


Figure 2 - Coding of interview transcripts

Each node can be analysed in turn and manipulated. Figure 3 shows the manipulation options for 'Motivation', which is node address (1).

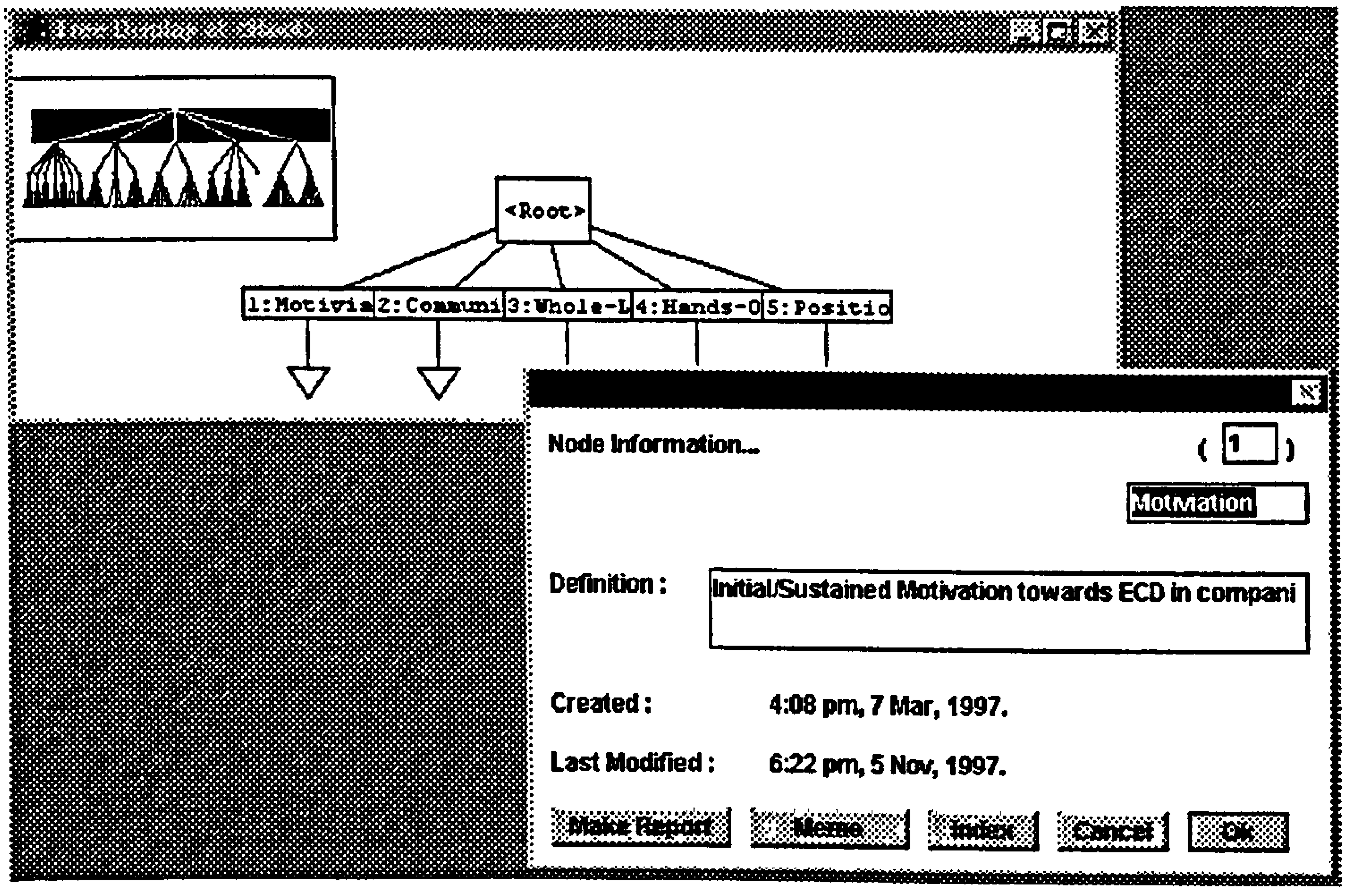


Figure 3 - Building a theory by forming categories

The data analyst can either:

- make a report of all text indexed under this node (allowing for the data from many documents to tell a story about 'Motivation in this case);
- write a memo relating to this node (allowing for a description to be recorded of what importance the analyst gives to this node, and what their conclusions are about the report they have made for this node); or
- index the node (thus adding more text units to the node, or changing the location of the node to fit with similar nodes in different areas of the tree structure.

It is by the constant re-addressing of nodes and consideration of memos in the NUD•IST software that the tree structure is pruned to give an acceptable description of the qualitative research topic, so building a theory

The tree structure for this research project resulted in 138 nodes, which cascaded from five top-level nodes, and is represented in a linear fashion in the remainder of this appendix.

```
Q.S.R. NUD.IST Power version, revision 3.0.4d GUI.
Licensee: Tim McAloone.

PROJECT: DEEDS, User Tim McAloone, 4:45 am, 30 Jan, 1998.

(1)         /Motivation
(1 1)       /Motivation/Standards & Regulations
(1 1 1)     /Motivation/Standards & Regulations/In Compliance
(1 1 2)     /Motivation/Standards & Regulations/Requirements
(1 1 3)     /Motivation/Standards & Regulations/Labels
(1 1 4)     /Motivation/Standards & Regulations/Internal Envtl. Standards
(1 1 5)     /Motivation/Standards & Regulations/Global Issues for Standards
(1 1 6)     /Motivation/Standards & Regulations/Self-Regulation & standard setting
(1 2)       /Motivation/Customer-Driven
(1 2 1)     /Motivation/Customer-Driven/Lease-Market
(1 2 2)     /Motivation/Customer-Driven/Product Liability Contracts
(1 2 3)     /Motivation/Customer-Driven/Stringent Research
(1 3)       /Motivation/Corporate-Driven
(1 3 1)     /Motivation/Corporate-Driven/Bottom-Up Down
(1 3 2)     /Motivation/Corporate-Driven/Standards
(1 3 3)     /Motivation/Corporate-Driven/Driving Force
(1 3 4)     /Motivation/Corporate-Driven/Communication, Contact
(1 3 5)     /Motivation/Corporate-Driven/Membership of...
(1 3 6)     /Motivation/Corporate-Driven/Education
(1 3 7)     /Motivation/Corporate-Driven/Top-down
(1 4)       /Motivation/EH&S-Driven
(1 4 1)     /Motivation/EH&S-Driven/Audits
(1 4 2)     /Motivation/EH&S-Driven/As Environmental Driving Force
(1 4 3)     /Motivation/EH&S-Driven/As Authenticators of DFE
(1 4 4)     /Motivation/EH&S-Driven/Don't Need EH&S yet
(1 5)       /Motivation/Business-Driven
(1 5 1)     /Motivation/Business-Driven/Enthusiasm, trend-setters
(1 5 2)     /Motivation/Business-Driven/Communication, driving force
(1 5 3)     /Motivation/Business-Driven/Business Decisions
(1 5 4)     /Motivation/Business-Driven/Champion in each business
(1 5 5)     /Motivation/Business-Driven/Many units under one umbrella
(1 5 6)     /Motivation/Business-Driven/Key to successful implementation
(1 6)       /Motivation/Middle-Management
(1 6 1)     /Motivation/Middle-Management/Presentation, enthusiasm
(1 6 2)     /Motivation/Middle-Management/biggest problem
(1 7)       /Motivation/Design-Group Driven
(1 7 1)     /Motivation/Design-Group Driven/No link to real environmentalists
(1 7 2)     /Motivation/Design-Group Driven/Design group driven
(1 7 3)     /Motivation/Design-Group Driven/Champion needs teams
(1 7 4)     /Motivation/Design-Group Driven/Education
(1 7 5)     /Motivation/Design-Group Driven/Teams
(1 7 6)     /Motivation/Design-Group Driven/Enthusiasm
(2)         /Communication
(2 1)       /Communication/Envtl. Info. Supply
(2 1 1)     /Communication/Envtl. Info. Supply/Collocation
(2 1 2)     /Communication/Envtl. Info. Supply/Corporate Information, education
(2 1 3)     /Communication/Envtl. Info. Supply/Membership of external socs. & insts.
(2 1 4)     /Communication/Envtl. Info. Supply/Workshops & reports
(2 1 5)     /Communication/Envtl. Info. Supply/Five Minute solution
(2 1 6)     /Communication/Envtl. Info. Supply/Talk the right lingo
(2 1 7)     /Communication/Envtl. Info. Supply/Culture change
(2 1 8)     /Communication/Envtl. Info. Supply/Information sharing...
(2 1 9)     /Communication/Envtl. Info. Supply/Enthusiasm
(2 2)       /Communication/Supplier Relations
(2 2 1)     /Communication/Supplier Relations/Including suppliers in design
(2 2 2)     /Communication/Supplier Relations/suppliers as source of info. & help
(2 2 3)     /Communication/Supplier Relations/Co-operation = good information
(2 3)       /Communication/Environmental Champion
(2 3 1)     /Communication/Environmental Champion/Design Carryover
(2 3 2)     /Communication/Environmental Champion/Checking up, caution required
(2 3 3)     /Communication/Environmental Champion/Opportunity
(2 3 4)     /Communication/Environmental Champion/...as teacher
(2 3 5)     /Communication/Environmental Champion/Driving Force
(2 3 6)     /Communication/Environmental Champion/Enthusiasm
(2 3 7)     /Communication/Environmental Champion/Problems
(2 3 9)     /Communication/Environmental Champion/Implementation & Info. Conduit
(3)         /Whole-Life Thinking
(3 1)       /Whole-Life Thinking/Ecology=Economy
(3 1 1)     /Whole-Life Thinking/Ecology=Economy/Negative cost perceptions
(3 1 2)     /Whole-Life Thinking/Ecology=Economy/Good ecology = good economy
(3 1 3)     /Whole-Life Thinking/Ecology=Economy/Data required to prove above
(3 1 4)     /Whole-Life Thinking/Ecology=Economy/Asset management works!
(3 1 5)     /Whole-Life Thinking/Ecology=Economy/Future competitive edge
(3 1 6)     /Whole-Life Thinking/Ecology=Economy/Whole-life design
(3 2)       /Whole-Life Thinking/Asset Management
```

(3 2 1) /Whole-Life Thinking/Asset Management/Product Maturity alters freedom
(3 2 2) /Whole-Life Thinking/Asset Management/Dematerialisation
(3 2 3) /Whole-Life Thinking/Asset Management/Product liability contracts
(3 2 4) /Whole-Life Thinking/Asset Management/recovery centres
(3 2 5) /Whole-Life Thinking/Asset Management/Customer relations
(4) /hands-on ECD
(4 1) /hands-on ECD/Phases of Design
(4 1 1) /hands-on ECD/Phases of Design/Early in design
(4 1 2) /hands-on ECD/Phases of Design/Later in design
(4 1 3) /hands-on ECD/Phases of Design/Use, longevity
(4 1 4) /hands-on ECD/Phases of Design/Design carryover, redesign
(4 1 5) /hands-on ECD/Phases of Design/Focus on new products to reduce investment
(4 1 7) /hands-on ECD/Phases of Design/Engineering Specification
(4 1 8) /hands-on ECD/Phases of Design/Scheduling env. issues
(4 1 9) /hands-on ECD/Phases of Design/Parallel to quality
(4 2) /hands-on ECD/Features of Design
(4 2 1) /hands-on ECD/Features of Design/Communicating criteria to suppliers
(4 2 2) /hands-on ECD/Features of Design/Materials choice
(4 2 3) /hands-on ECD/Features of Design/Manufacturing process design
(4 2 4) /hands-on ECD/Features of Design/Qualitative dominates quantitative
(4 2 5) /hands-on ECD/Features of Design/Design for EOL
(4 2 6) /hands-on ECD/Features of Design/Design for whole life = different issues
(4 2 7) /hands-on ECD/Features of Design/Packaging
(4 2 8) /hands-on ECD/Features of Design/Longevity & carry-over designed-in
(4 3) /hands-on ECD/Tools etc.
(4 3 1) /hands-on ECD/Tools etc./Lack of tools
(4 3 2) /hands-on ECD/Tools etc./Part of design model
(4 3 3) /hands-on ECD/Tools etc./Ease of use, streamlining
(4 3 4) /hands-on ECD/Tools etc./Prioritising
(4 3 5) /hands-on ECD/Tools etc./Qualitative is good
(4 3 6) /hands-on ECD/Tools etc./Report-type of tool
(4 3 7) /hands-on ECD/Tools etc./Checklists
(4 3 8) /hands-on ECD/Tools etc./Workshops
(4 3 9) /hands-on ECD/Tools etc./Pilot studies
(4 3 10) /hands-on ECD/Tools etc./Tear-down analysis, DFD
(4 3 11) /hands-on ECD/Tools etc./Matrix approach, target plots
(4 3 12) /hands-on ECD/Tools etc./LCA & other computer tools
(4 3 13) /hands-on ECD/Tools etc./Corporate standards
(4 3 14) /hands-on ECD/Tools etc./Data for proof...
(4 3 15) /hands-on ECD/Tools etc./Steal other people's tools!
(4 3 16) /hands-on ECD/Tools etc./Personalised tools
(4 3 17) /hands-on ECD/Tools etc./General awareness
(4 3 18) /hands-on ECD/Tools etc./Outside consultants
(4 3 19) /hands-on ECD/Tools etc./The Holy Grail
(4 4) /hands-on ECD/Concept Demonstrators
(5) /Positioning in 'The World'
(5 1) /Positioning in 'The World'/Direction
(5 1 1) /Positioning in 'The World'/Direction/Champion in each business
(5 1 2) /Positioning in 'The World'/Direction/More bottom-up pull
(5 1 3) /Positioning in 'The World'/Direction/Low-hanging fruit...
(5 1 4) /Positioning in 'The World'/Direction/Close control...
(5 1 5) /Positioning in 'The World'/Direction/More than one lifetime's work!
(5 1 6) /Positioning in 'The World'/Direction/Good progress
(5 1 7) /Positioning in 'The World'/Direction/Asset Management
(5 1 8) /Positioning in 'The World'/Direction/Investment now = benefits later
(5 2) /Positioning in 'The World'/Problems
(5 2 1) /Positioning in 'The World'/Problems/No Holy Grail exists
(5 2 2) /Positioning in 'The World'/Problems/Evangelism Required
(5 2 3) /Positioning in 'The World'/Problems/Materials-specific
(5 2 4) /Positioning in 'The World'/Problems/Credibility problems...
(5 2 5) /Positioning in 'The World'/Problems/Cost
(5 2 6) /Positioning in 'The World'/Problems/Staff turnover
(5 2 7) /Positioning in 'The World'/Problems/Compliance with law

appendix 2

DEEDS project information

DEEDS stands for **DE**sign for **E**nvironment **D**ecision **S**upport. This three year research project is sponsored by the Engineering and Physical Sciences Research Council (EPSRC) and carries project numbers GR/K69728 and GR/K69346. The following text is taken from a press release and explains the aims and objectives of the DEEDS project.

DEEDS

DEsign for Environment Decision Support

Background

Environmental concerns are becoming increasingly important to manufacturers, driven by consumer pressure, legislation, standards, the need to maintain a competitive advantage or the desire to be a good corporate citizen. Design is an ideal opportunity to significantly reduce the environmental impact of manufactured products at the earliest possible stage.

Major manufacturers world-wide are responding to the environmental challenge. In the USA, Xerox has saved approximately $500 million a year through the reuse of photocopy components whilst in Japan Hitachi has placed 150 patents on designs for disassembly. The immediate challenge for designers and manufacturers is to develop products that have a reduced environmental impact across their life-cycle including extraction of resources, processing, manufacture, use and disposal.

Currently there is little information and few proven tools to support the successful integration of environmental issues into the design process. The Engineering and Physical Sciences Research Council funded project DEEDS arose from manufacturers requests for a systematic approach to Design for Environment.

The aim of the project is to produce a set of practical and effective techniques for industry use. This will include tools such as; design guidelines, computer aids, databases and training schemes In addition to these methods, an integrated model of the environmentally conscious design process will be developed. This model will enable a better understanding of the process of environmentally conscious design and the organisation of environmental initiatives such as energy conservation and recycling schemes.

Collaborators

The industry collaborators in the DEEDS project are ICL plc. and Electrolux Floorcare UK. Both of these firms are at the forefront of serious environmental management, engaging in the analysis of their products and operations. Both firms are contributing substantial resources and stand to gain as UK leaders in Environmentally Conscious Design.

Further collaborators include the Industry Council for Electronic and Electrical Equipment Recycling (ICER), and Mayer Cohen Industries. ICER is a broad based association which draws together suppliers, manufacturers, retailers, recyclers, waste management companies and local authorities to work with the Government to increase recycling of electronic and electrical products in the UK. Mayer Cohen, ICL and Electrolux are among its members. Mayer Cohen will assist the DEEDS project with practical recycling expertise. Mayer Cohen have been recycling products for over 10 years and are experts in recycling plastics and are now developing technologies to recycle problematic waste such as cathode ray tubes.

The Research Team

Two research groups will undertake complementary parts of the DEEDS project. The Manchester Metropolitan University group will emphasise development of tools by working closely with designers: "learning by doing". The second group from Cranfield University will observe the decision-making process: "learning by watching".

The Cranfield research group, based at The CIM Institute, will observe and analyse the environmentally conscious design process with the collaborating manufacturers, and in identified best practice companies. The objective is to develop a model of these companies Design for Environment practices.

Cranfield will also asses the success of new environmentally conscious design tools and techniques within the companies. This will enable the development of systems necessary for the successful integration of environmental factors into the design process.

The Manchester Metropolitan University research group will locate and develop simple, useable methods for Design for Environment. This will focus on key decision points identified by Cranfield and the collaborating manufacturers. The aim is to develop tools and methods which will allow the companies to significantly reduce the environmental impact of their products during the DEEDS project and beyond.

Research Objectives

- To build models of environmentally sound decision making in design by observing and analysis
- To develop and test generic methods and tools to assist the provision of environmental information
- To evaluate the tools, methods and the decision-making model by in-house implementation

Outcomes

Throughout the three year project the results of the project will be documented and disseminated across the electrical, electronics and other industry sectors. Through our collaboration with ICER this information will be readily accessible. The key outcomes of the project are:

- a set of practical, effective and proven tools to improve the environmental performance of products;
- an integrated model of the environmentally conscious design process, validated by mapping onto the individual companies.

appendix 3

interview structure

The enclosed interview structure was used to prime candidates for their interviews. It contains five areas which the author based the interviews around. Interviews were of a semi-structured nature and lasted between one and two hours. The demographics collected in this document were used for the DEEDS project alone and not for the PhD research.

Cranfield UNIVERSITY

The CIM Institute
Cranfield University
Cranfield Bedford MK43 0AL. UK.
[Date]

Tel: +44 (0)1234 750111 ext. 2854
Fax: +44 (0)1234 750852
EMail: tmcaloone@cim.cran.ac.uk

[Mr/Mrs/Ms]
[Company Name]
[Address1]
[Address2]

Dear [name],

Visit To [Company Name]

Thank you for agreeing to be interviewed on [date]. I enclose a demographic questionnaire so that we may categorise our interviews by company type and ensure a fair representation of the industry, when we come to the data analysis phase of our project. If you could fill this in before the interview, I will collect it and run through any queries you may have when I visit you.

I also enclose a short description of the types of question I will be asking in the interview, which will hopefully prepare you for what to expect. Please do not nesitate to contact me if you have any queries regarding the questionnaire or the interview outline.

I look forward to our meeting.

Yours sincerely,

Tim McAloone.

The CIM Institute
Cranfield University

World-Wide Industry Survey:
Integrating Environmental Decisions Into The Design Process

DEEDS
DEsign for Environment
Decision Support

Demographic Questionnaire

Introduction

The purpose of this questionnaire is to collect general information regarding your company's business operations and approach to environmental considerations faced during new product development. The information will be most useful in helping to categorise and associate data during analysis.

All information will be treated in strict confidence; if there are any points you do not wish to divulge, please feel free to leave the space blank. If there are any issues you would rather discuss before committing to paper, these can be left until the interview.

Company Information

Your Name:

....

Position:

....

Company Name:

....

Company Address:

....

....

....

Zip-code ....

Telephone Number
....

Fax Number
....

EMail
....

Brief Details About Your Company....

1. Is your company part of a larger organisation?
Yes [ ]1 No [ ]2 *...proceed to question 2*

If yes, what is the name of your parent company?

____

2. How many employees do you have on the site where you work?
(Please tick the __most__ appropriate response)

(a) <500	[ ]a
(b) 500-999	[ ]b
(c) 1000-1999	[ ]c
(d) 2000-3000	[ ]d
(e) >3000	[ ]e

3. Which of the following business activities are carried out at the site where you work?
(Please tick the __most__ appropriate responses)

	On-site	Off-site*	Not at all	
(a) Marketing	[ ]a	[ ]a	[ ]a	
(b) Research	[ ]b	[ ]b	[ ]b	
(c) Product Development/Design	[ ]c	[ ]c	[ ]c	
(d) Production/Process Development	[ ]d	[ ]d	[ ]d	
(e) Manufacturing/Production	[ ]e	[ ]e	[ ]e	
(f) Environmental Research/Support		[ ]f	[ ]f	[ ]f
(g) Administrative Services (Finance, Personnel etc.)		[ ]g	[ ]g	[ ]g

**** Off site activities are those carried out by a sub-contractor or sister company***

The products manufactured by your company.... (if you do not manufacture any products, please proceed to question 6)

4. What sort of products are manufactured by your company?

____
____
____
____
____
____
____

5. Please indicate how new and/or original your current full product range is by entering a percentage (approx.) against each of the following categories:
(Please tick __all__ the appropriate responses)

(a) True Innovations (Products that are new both to the company and the world)	[%]a
(b) New Product Lines (Products which are new to the company and allow entry to new markets)	[%]b
(c) Product-Line Extensions (Products that are new to the company but, are part of an existing product family)	[%]c
(d) Product Improvement/Modifications (Products which offer improved performance to customers)	[%]d

6. How would you classify a successful <u>new</u> product?

(Please rank the factors in order of importance - rank 1 those factors deemed most important, through to rank 5 those factors deemed the least important. Please note: tied ranks are acceptable)
(Please tick <u>all</u> the appropriate responses)

(a) Products which achieve **cost** targets [ ]a
(b) Products which achieve **profit** targets [ ]b
(c) Products which achieve **quality** targets [ ]c
(d) Products which achieve **time** targets [ ]d
(e) Products which achieve **sales** targets [ ]e
(f) Products which achieve **environmental** targets [ ]f
(g) Other [ ]g
(Please specify)

____

Thank you for spending the time to complete this questionnaire.

Please retain this questionnaire until
Tim McAloone visits your company. Thank you.

Interview Outline

There follows a brief outline of the questions I will be asking in my interview, to prepare you for the day. The interview should last no longer than 90 minutes, but may do so if you wish.

I would like to take this opportunity to ask if I may record the interview on micro-cassette. The idea of this is two-fold:

- to provide a more natural flow to the interview (and avoid interruptions whilst note-taking);
- to aid me when reporting the interview.

All cassettes will be destroyed, or returned to you if you prefer, and a copy of the transcript will be available for you to check. If, however, you prefer that I did not use a dictaphone, I will gladly respect your wish.

Outline of interview questioning

The interview will revolve around five main topics, which are described in more detail below.

1. Top Management Commitment

In this part of the interview I would like to find out what level of support is supplied by your organisation's management, with regard to the implementation of environmental considerations into the design process. I would like to from where this commitment came and how important you feel it is to your operations. If you feel that you do not have top management commitment to environmental issues, I would like to know how you feel about your achievements, despite the lack of management support - does this situation require environmental 'champions'? If so, at what level?

2. Design Methods

This section attempts to go into more detail about the way in which you integrate environmental issues into design. Do you have a formalised environmental design model? Do you have a strategy for analysing a product's environmental hot-spots, and then tailor a design model to that? How important do you feel the timing of environmental design tools is to their successful integration into design?

3. Team-working

I am trying to understand how important a team environment is when designing an environmentally conscious product. Do you feel your product designs require a great deal of teamwork and a highly motivated team-leader to ensure environmental success, or must the design be handed over at one specific stage of the process for strict environmental scrutinisation by specialists?

4. Tools

Here I would like to know what type of tools you use to ensure that environmental considerations are streamed into design. These tools may be in the form of software, handbooks, workshops, checklists, etc. Do you have any examples of these tools?

5. Problems

In this section of the interview I would like to understand how companies can avoid the pitfalls, when designing an environmentally conscious product. I will therefore be asking what problems you have encountered with tools, with integrating new environmental criteria into old and established design methods, and with motivating and educating your workforce to achieve continued environmental improvement during design.

appendix 4

sample interview transcript

The following is one of the twenty four interview transcripts collected in the sector-wide survey, and used in the data analysis for this research. For confidentiality reasons, certain areas of text have been replaced with text in [square brackets].

Interview with Environmental Champion
Company B
1997

Transcribed by Tim McAloone (=TM) Environmental Champion (=EC)

TM *Could you briefly start by telling me just where you fit in to the design for environment arena at* [Company B]*?*

EC OK. This laboratory is the research and development part of [Company B]. There has been a partnership over the past four or five years I suppose between the [Company B's] R&D effort and the Corporate staff who deal with Environmental Health and Safety [EH&S] issues, and several of the business units that are the actual places where things get implemented. The people who have the substantial part of their activities in this effort probably number no more than a dozen, but if you evaluate in terms of the number of people in the business units that have this as one of the whole list of things that they think about it would be a considerably larger number.

TM *OK.*

EC Within the research area of this laboratory there have been three or four people depending on exactly how you count, that have had this as one of their main efforts, and the others have largely been dealing with looking at practical problems or practical challenges that have come up in the factories, such as the use of recycled plastic materials, things like that, and trying to optimise and develop things like that to make implementation feasible or easier, or more economically sensible or whatever. What I have been principally doing is been to try to lay the intellectual ground-work for the whole activity and to link the Design For the Environment activity as closely as possible with environmental science. Because my perception is that even though DFE advertises itself as beneficial to the environment there is in fact almost no connection between DFE people and environmental scientists, and therefore, it is a very chancy argument to make and I think the argument *can* be made but you have to get busy and do it and that is what I have primarily been doing in the past two or three years as well as having been trying to communicate this vision to our design teams, and in a broader sense, to the world at large.

TM *In terms of* [Company B], *where does the environmental commitment come from, and what role do top management play? How did the whole thing start up?*

EC I think the original commitment probably came when [my colleague] and I decided that this was an important issue and we started raising the issue. Eventually this was incorporated or bought-into by, I think first the Corporate staff people and eventually the chairman of the Corporation agreed to issue a certain set of values that included things that we were calling Industrial Ecology and Design For the Environment, and some other rather specific things like, no use of ozone depleting gases and so forth. So I think the initial commitment was in a sense bottom-up commitment, but it eventually managed to make it all the way to the top with a statement from the chair.

TM And do you think before that within [Company B], *were there any Design For Environment activities going on before you started?*

EC No I think not. We began this probably in 1991 maybe.... and at that time it's probably fair to say that nobody any place was really much further than that. Everyone was in the process of figuring out exactly what this all meant.

TM OK, since then, after you gained top management commitment, how has it actually spread from going from yourself upwards and back down again?

EC The business units are fairly independent and I think it is fair to say that some of them have been considerably more enthusiastic about it than some others, and I think at this stage we have got most of the units, it doesn't mean that all the design teams within that unit are necessarily active in it, but my experience has been that generally design teams tend to be made up of fairly young engineers and the young engineers see this as an important thing to do. But they have never had any training in it, and so you have to show them what to do, and once you do that then usually they are on board.

TM You mentioned design teams just then, are they multi-functional teams? How do you present environmental considerations to them?

EC There again I think that varies a little bit with the sub-organisation, but they tend to be quite multi-functional. The attempt certainly is to include not only the design people but manufacturing people, product packaging, if there is a strong research component still that has to feed into it, then somebody from our laboratory will probably be a part of it.

TM If I were a member of one of these teams, how would I actually know if it was a Design For the Environment, is it within the design models, or product spec.?

EC It is for some. It is for some. One particular machine, which is a very large computer that takes information, transfers it to long distance networks, and so forth, the design rules and formats and software for that system have things embedded in them. And, in other parts the most efficient way that we get the word out is that every year there is a Corporate-wide meeting of designers to share information and we have tried hard to have presentations and workshops at those meetings so that - we aren't going to reach all the people that way - but the hope is that we will reach somebody in each team who will then bring the message back. One of the things that I have done, and several others have done a lot of over the last two or three years has been that a design team will call us saying, 'We have a product that is in design and we are getting ready to design it, or we are thinking of a re-design, will you come and give us an assessment of how you think it is doing on environmental responsibility?'.

TM *Would you come along fairly early in the design process there?*

EC We have seen everything. The ideal is coming very early before they have made any decisions at all, and sometimes we manage to do that. With some products though that are already in manufacture we have done some of those and we can still make some useful changes although they are easiest there in product packaging, shipping and installation, things that aren't quite so embedded in the actual design of the product. If you get something early-on then you can more easily, from the choice of materials, how things are put together and so on.

TM *OK Right. So what tools would the designer have at their disposal apart from yourself and the department to come along in their everyday lives, designing for the environment, what tools, software or checklists are there?*

EC There are, I don't know if you might be familiar with our matrix design approach?

TM *Was this presented at the Edinburgh conference?*

EC Yes. Probably. What we have done is to develop checklists for each of the elements of the matrix that the designers have available to them. We have not really ever felt that there is any software that really does the job in this business, although we have played a little bit at doing some ourselves, we've looked at some of the commercial software and at this stage we have not felt that any of it is .....

TM *What sort of software have you looked at, Design For Disassembly software, or Life Cycle Analysis...?*

EC Life Cycle Analysis software. Generally that requires extensive knowledge of not only the materials involved, but also the amounts of materials, and that is information that we don't usually have early in the design process. By the time you have it, it is late in the design process, most everything is frozen! So even though conceptually, that is a nice way to understand the systems and be quantitative about it, in practice it has been almost totally unusable in our view.

TM *What about Abridged LCA, have you looked at that?*

EC I'm sorry?

TM *Abridged Life Cycle Analysis?*

EC Well that's, that's really what we do I think. Although, we started out by calling it 'abridged', and we are now calling it 'streamlined', the distinction being that 'abridged' suggests that you may be deleting parts of it. For example, you only treat what happens inside your gates, and we feel strongly that all phases of the life stage are very important, and so we don't want to abridge in any way but we want to streamline the whole process so that rather than doing one of these 'for six months everybody goes slowly and tries to get everything right' operations. With our streamlining matrix approaches we really can do it in about a day or two with the design team - and you would get a day or two with the design team. But, six months you might get once, you will never get it again, and you have probably heard this at other places.

TM *Yes.*

EC We have found that a day and a half, two days, you can get that every time, and you can get an awful lot done. In fact I would claim that there are very, very few decisions, maybe none that the designer would make differently having had a six month assessment, or a two day assessment, because very few of the designers' decisions are based on quantification, they usually do not have a choice of using 2kg of something, or 1kg of something. If they need to make a housing they might be able to shave it a little bit but basically they have to make that housing! It has to be so big, and so the decisions that you are more likely to get are, 'What is the material going to be?' which is independent of how much, and 'Are you going to put a marking on it so that you know what kind of plastic it is?', again it is independent of how much. And our experience has been that almost anything we can think of that is actually going to be implemented by the design team is qualitative information not quantitative. And this plays into the fact that you can pretty efficiently give a qualitative assessment in a short period of time and a quantitative assessment takes much, much longer.

TM *Do you go back to the design team for each product design, so for example do you manage to see one design team for one product and go back to them again and see if they have learnt anything from previous performance?*

EC Sometimes. Again it is kinda dependant on who asks, but of course we talk to them.

TM *Have you seen improvements in these people? I suppose if they are going to ask you back then they must have moved on in some way!*

EC Yes that's right, you tend to see the improvers, but yes I think we can say that. The ideal is that after you have done one or two with the design team then they start to embed it into their software and into their thinking, and they will get at least 50 or 60% of what you might recommend automatically because some things are different assessment-to-assessment but within a general type of industrial product, electronics case, an awful lot of the advice tends to be the same, no matter what product you are looking at: minimise use of energy; mark your plastics; don't choose toxic materials.... So there is a whole set of things that you need to bring to their attention but it almost doesn't matter what you design. And then there are other things that get specific when you get down to specific choices of materials, 'How you put things together and making a choice?', 'How you get your box shut-up', and that sort of thing, which is sometimes individual.

TM *Are there many trade-offs that need to be made? For example, between the normal designer's Design For Assembly rules and when they come to Design For Disassembly, are there a lot of trade-offs that you have come across there within your products?*

EC I think it is fairly early to be definitive about it but our feeling at this stage is that things that assemble efficiently, disassemble efficiently. So the Design For Assembly people like a small number of parts, they like minimal use of different materials because that plays into fewer things that have to be put together and they like quick and simple ways to fasten things together and these are the sort of things that if you do in reverse most of them work out nicely at the end-of-life. There are some things that involve joining of dissimilar materials that might be fairly efficient on the front-end but might be difficult on the back-end and so sometimes these issues come up and then you do have a trade-off situation.

TM *And there are a set number of rules that the designers can then follow recognise what to do that you've drawn up for them?*

EC No. I would say the whole business resists laying out a neat framework pretty effectively. We have sort of standard bits of advice that seem to go along and a lot of those we can embed in some design software, but a lot of things we really can't. It is partly because you have this big trade-off situation, and partly because the environmental issues are complicated and also because environmental science keeps going forward so an issue that, well, CFC's is an example. Thirty years ago that was a great thing, and we now know it is not a great thing, and it is because science has gone forward. And there are doubtless some things in what we are doing today that will change as time goes on, but to go back to one of my first points, the better we understand how environmental science is doing today. And what it is interested in, and where it is likely to go, the less likely we are to do things that will create concerns ten or fifteen years later.

TM *What, at this stage, do you think is important to the design of a product being successfully designed within environmental issues in mind? Do you think that it requires one particular person to drive the design through, or is it very much based on the environmental science behind the design?*

EC I, at this stage many of the decisions that are being made, I think can be pretty simple, and don't require expensive wrestling of issues with the environmental scientists. It's using less material, and using less energy, something like that - almost automatically it can't be a bad mistake. And there are still, because this is such a young field, because people, many design engineers are only in the processes and hearing about it for the first time, or they have only heard about it a couple of years ago and they haven't had their next design to work on. So we have got many of these fairly straight forward things that are still available and I think that is where the thrust, at least within our company, and I suspect within most companies, it is just to get the obvious.

TM *It is really taking the low hanging fruit first?*

EC Yes. Later on we will need to put up our ladders and climb up the tree to get the stuff at the top, but I think that's a way off really! I would much rather have a million designers today doing the things that are likely to be right than have them wait around for ten years until we really figure out the optimum, because first of all we are never going to get there, and second of all ten years of having implemented a lot of the obvious things over products that are flowing out of the factories is going to do an awful lot of good. So I want to do a lot of the simple things right now. And as we learn more then we will do the more complex things, and we want to do those as well, but first things first and right away.

TM *In terms of the everyday design of a product, what provisions are made for design carry-over, and experience to be carried over for future designs?*

EC When we put it into the software that, by that I mean the, many design teams have design checklists or design guidelines that are part of their software packages, so it's not specifically DFE or LCA software, it is sort of embedded within what they do everyday. And there the carryover is automatic, and the things in there are going to be the simplest things, the more straightforward things that a designer with little training in DFE will know whether it has been done or not.

TM *OK. And who has control over that software? Design management?*

EC Generally the design management in the organisation, because they will want it to flow to all their design teams.

TM *Right. I see so they are basically trying to standardise it across their business?*

EC Across that business unit. Yes.

TM *So in terms of the design process, do you work to a formalised design model, like a gate-review process? If so, how do you integrate environmental issues into it?*

EC Yes, aha.

TM *Yes. And there are certain environmental considerations that are made in each gate review?*

EC There might not be at every gate, but at some of them.

TM *Right. Is that offered in terms of an analysis at each of the gates or.... I am trying to see the difference between an after-the-event analysis and an on-hand situation....?*

EC Right. Well I think the ideal would be that.... I am not sure I have got all these gates firmly in mind.... I guess the first one is 'Concept', and the second is 'Deciding to go ahead', and it is at that stage, or maybe after you have got the design roughed out that you would like to get into your assessment, and then later phases would be checking to see whether you have picked up the recommendations that came out of that first stage, or at least considered them - we aren't going to have every recommendation implemented because for some of them there will always be other pressures, er, cross pressure or a lack of a reliable supplier for something that you would prefer to use but you can't afford to if you don't have a good source; there's all sorts of things that come into play, but the goal is to get the environmental issues on the table to be part of the discussion and then many of them will happen and not all of them probably. As with every other thing, no design is as light-weight as you would like it, no design is as long-lived as you would like it.

TM *It is perhaps good because it leaves room for improvement any way!*

EC Well that's right, that's right. But as you probably know design teams have this multiplicity of goals and somehow the idea is to optimise the steps, rather than optimise any one of them.

TM *Yes. Someone actually tried to describe the design process as being an inverted explosion, when you have got all these things flying around and then all of a sudden somehow they come together and everyone else thought that was quite a good way of describing it.*

EC Yes! Excellent.

TM *In terms of problems that you have experienced on the way, what would you say have been the biggest problems when changing from Design to Design For the Environment?*

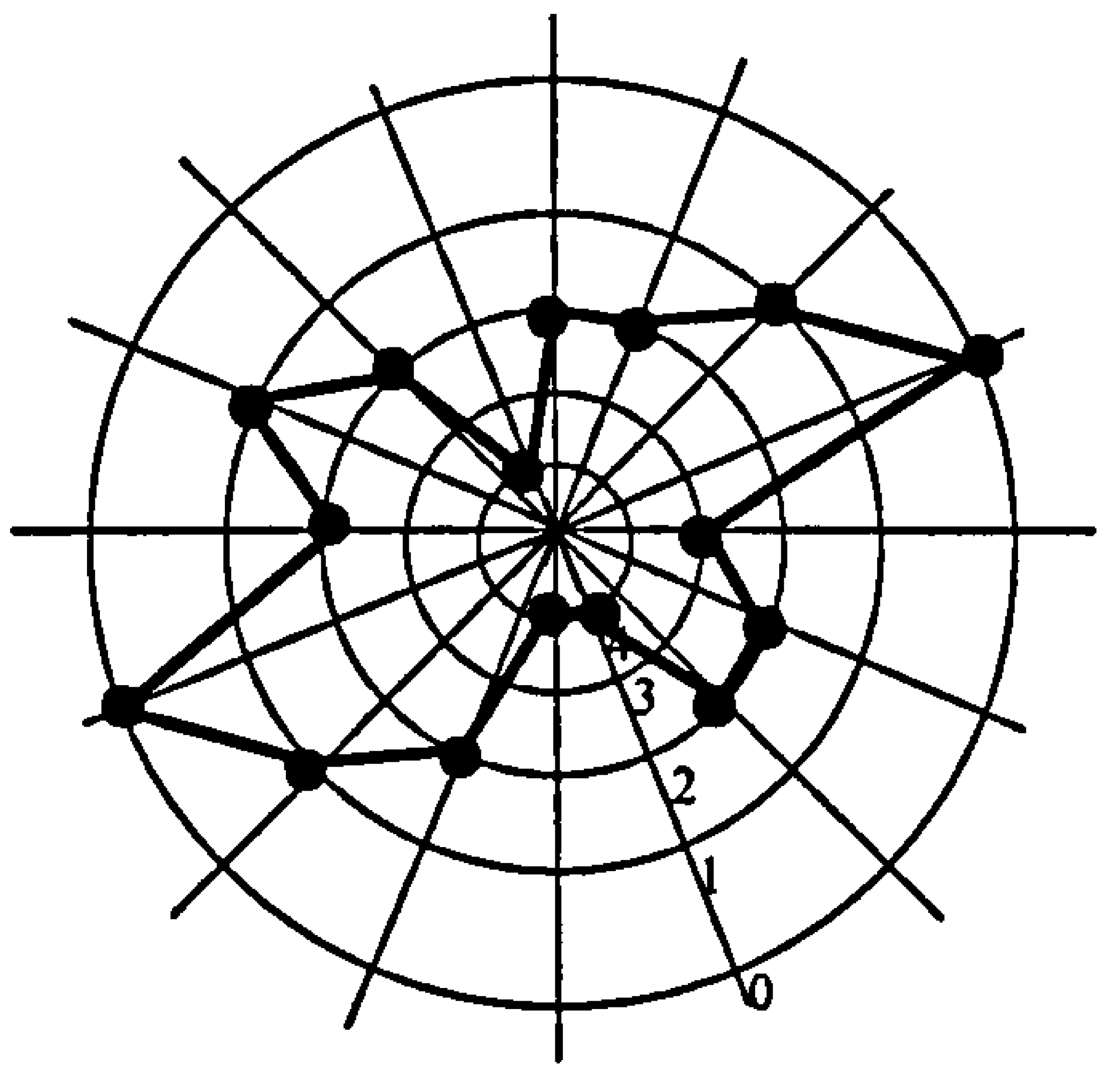
EC Well, I think part of it is the perception that anything labelled 'Environment' is going to be costly and divisive and divert your attention from what your real business is. That stems in part from the fact that for two or three decades the only place environmental issues have come in is in the regulatory area and it always costs money, and they have always been a bit of annoyance, and so the most senior managers who have lived through this instinctively see that as what 'Environment' means and the concept of designing in such a way as to look forward and avoid that sort of thing in the future takes a while to get into the thinking. And so I think it is probably getting the new paradigm into the middle management that is the biggest challenge.

TM *It is very interesting that you say that, that is exactly the same comment that I had yesterday from another company, and that is they have the bottom-up commitment and the top-down commitment, but it is the middle bit that they have difficulty with, and they reckon....*

EC The more examples one has of success at this, these are just to show people quite how we get them into the idea of that they may well save money, their customers may well choose them because of the environmental responsibility for their design, their employees will like it, there is a suite of good examples that we are building up and we and Xerox and everybody else tend to trade the things that don't get into corporate secrets because we all need them. And using somebody else's example is OK too.

TM *In terms of that do you have any, within your design tools and strategies, do you try and aim things so the designer can see straight away - I suppose your matrix goes some way to doing this - it shows straight away that they have made an improvement in their decision towards the environment?*

EC Yes we have used that, and we also use what we call target plots. We used generic automobiles as an example that we thought people could relate to, and we explain here the reasons for our ratings. We use the integers between 0 and 4, and nothing else, and that helps us do it quickly because if we had to argue about 3.1, or 2.6, it would take longer, but the advice doesn't change. So one way to streamline is to limit the number of possible choices. And then here, a completed matrices which you can look at, but here are the target plots.



The idea here is that the matrix is five life-cycle stages and five environmental concerns, so you have 25 elements of the matrix. So if I take each one of those and draw a radial line here, so there is 25 radial lines and then we have got 4's to the middle and 0's here, and the 3's, 2's and 1's there, and like all targets, you want to get the shots near the centre, see. So anything that is outlyer, that one and this one, and that, and that, is immediately called to your attention. So when we do an assessment with our design teams we provide them with the matrix, the target plot, and we give them a series of recommendations. Then often what we will do is to say, 'If the recommendations are all implemented here is the new target plot'. So it is a 'before' and 'after' kind of thing.

TM *Right. So is that then their job, or their task to try to reduce the radius of this plot?*

EC Yes.

TM *How many iterations would you do of that?*

EC Depends on the team probably one or maybe two.

TM *And how successful has that been?*

EC My perception, I have talked about this a lot with inside and outside the company and it seems to be a concept that people find very comfortable, very easy to relate to, and so even though by it's nature it's not complicated I think that the beauty is that it is not complicated, that in ten minutes or so I can explain the whole thing from beginning to end, in enough depth so that the next time somebody sees one for the product that he or she is interested in, they know what it is about and they have an idea of how they can move on. We do one other thing for our designers, and that is that when we have our list of recommendations which have been done entirely on an environmental basis, we then take each one of the recommendations and we try to assess how that recommendation might influence cost on a product, how it might influence the time to market on a product, whether customers would notice it if you make an environmental change that you notice that's fine, but if you make one that your customer also notices, for one reason or another that is better, so we try to bring that out. There is one other one in there some place, but any way this gives you an idea of the fact that we try to take into some account the other concerns that a designer has to think about, and say, 'Well, this recommendation we think we can do right away, it won't cost you anything. People will like it'....

TM So that's your system of prioritising decisions?

EC Yes. Yes. And then with others, we try to always call out things that we are pretty sure they won't be able to do, but we still would prefer that eventually they would disappear, the use of certain materials that we don't have substances for, for example, where from a stand-point of knowing that it may be an environmental dis-benefit to some extent - we don't use things that are really awful, but there is a whole spectrum and you would rather have things that are completely benign: you never do have things that are *completely* benign, so there are always some things that are moving down the scale a bit. Almost all metals in the environment are, if they're laid by or get into water, the water system, copper and nickel and aluminium, and all the common things can be at least minor eco-toxics. So if we accept that we can move ourselves away from that, we try to do that. It isn't always possible but I always try to call it out for the designers so that they may hear of an alternative material next month that suits their needs, that I might not hear about and so the more they understand about the goals of the whole thing, the more likely we are over time to improve our products.

TM Someone explained to me that, in their opinion, certainly in the U.S. and elsewhere as well, a product isn't hazardous waste until you come to get rid of it and dispose of it. Do you take any account of the design process and try to design for reuse and do you actually do anything with these materials and with your methods, try and keep them within your system and remanufacture them at all?

EC It varies somewhat with product; we have, and have had for decades the practice of taking back [one of our products] and re-furbishing them and putting them back into service. We are now beginning to do the same thing with even some of our big machines, especially in Europe. There are all sorts of pressures to do it there, and it is stronger than either Asia or North America. And this is clearly something that we are moving towards more and more and so our design teams are beginning to think about it more and more. It's going to be an evolution clearly and our products have very, very different life-times which means that if you are designing a new product which has a life-time of two or three years... or may be six days, the way things are today (!), you can make a pretty good prediction of what your Corporation is going to be like when that reaches it's end-of-life, and what the recycling probabilities are likely to be in different parts of the world when it reaches the end-of-life. It is much more adventurous when you are dealing with something that is going to be in service for 15 or 20 years. So you have to do your best with that, but you have to also realise that it is going to be a different world and be fairly speculative.

TM *How do you judge the difference between actual life, and design life? For example, one of our research findings from the past is that certain products may have a design life of 18 years and an actual life of 18 months. How does your company match these two off? Is it therefore worth giving a design life of 18 years, putting all that effort and value add into the product, or would it be better to design for, say, five years and match it that way?*

EC I think it depends on your view of the future of the product to a large extent. There's a couple of approaches that have been taken to this sort of thing. In the case of [one of our products], we have been making the last few years two different, I say two different models - they aren't really different as far as the customer is concerned, but one is made with the idea that this will be sold to the customers, the other is made with the idea that this will be leased to the customers. The one that will be leased is built a little bit more ruggedly in several different ways, and a little more thought is given to how it can be refurbished, how it can be upgraded, because we anticipate that we might see that five times, or something like that. The other way to get at this, is to try to do modular designing where the frame of the equipment, you might think you are going to have forever and you have the shell, and much of the bulk of it really, but you might change the electronics. And if you design it with the idea of... lets use a computer example; if you change the processing chip, you might be able to get everything else out and give it an extra two years of life. And if one does a complete Life Cycle Assessment of equipment the two things that tend to come up when you think about longevity is, if it uses, if it's something that uses electricity then extending it's life will be an environmental benefit only if the electricity use is quite low. If you extend the life time of something that is a high electricity user, the overall environmental effect is probably going to be negative.

TM *Yes. And it is almost a line drawn between electrical and electronics?*

EC Well I am thinking here really of anything that uses power, if it's, it could be a refrigerator, it could be a computer, a cellular telephone.... If it's designed without thought to minimising power, or if five years later people figure out a way that it uses a tenth as much power, then extending the life of the original equipment is likely to be environmentally dis-favourable. If it is something that doesn't use power at all, or if it's pretty miserly on it's use of power then it is likely that extending the life is going to be an environmental benefit because you aren't going to have to do all the extraction of materials and manufacturing of something that is it's replacement. And it is areas like this where Life Cycle Assessment really comes into play, because that is a decision that is not going to be obvious from first principles.

TM *Do you think that* [your product] *will actually reach a plateau in terms of it's upgradeability and new design, because it can only get so small and the electronics can only get to a certain size? I was thinking of the example of photocopiers, they have got to a certain maturity in which there's only basic changes that can be made: do you think* [your product] *will actually get there?*

EC I think when one.... you are right about many things being related to the size of the human being: automobiles; bridges; buildings. There's all kinds of things that are related to the fact that a human is a certain size, and a keyboard is another example. What is likely to happen in our business.... communications and information are now thought of very broadly where almost daily it gets more difficult to separate the telephone, the fax machine, EMail, television, cable and everything else that brings the information in. I think what is more likely than having us get eventually to the smallest possible versions of each individual piece is that we will be throwing away many of the individual pieces and ending up with a very small number, maybe one, somehow or some tiny number of things that one has to deal with and they will incorporate all those services. So it will be a strong reduction in the amount of materials that get used per individual.

TM *Do you see a swing back to the past in the future, whereas before* [company B] *were de-regulated, you'd take back* [your products] *and refurbish them for completely different reasons, for example. Do you think or hope that that will be the future; how do you see it?*

EC I suspect it will be the future because I think our customers will demand it.

TM *OK.*

EC We have customers now, especially in Europe, that make that one of the provisions of the contract. The way they do it is not, 'We require you to take this back at the end of it's life', but 'We require you to take it back at the end of it's life if we ask you to'. Now the distinction there is that if you design something with end-of-life in mind it will have value at the end of it's life, as opposed to being something we have to pay £40 to dump in a hole some place. So the likelihood is that [a German customer] or whoever owns this thing will be able to sell it to a remanufacturing centre or something, and get some value back so that it's in their interest to buy something that retains some value even after it is no longer useable for what it has been designed for. If they find out that that isn't true and they sign one of these contracts, then they have the option of giving it back to us, and then we have to pay the £40 to dump it in a hole!

TM *Right. Do you see that as an opportunity for the future?*

EC Yes, absolutely! In fact I think the people that don't design that way will eventually design themselves right out of business. And so everyone is looking.... well if you are looking to do business for the next five years in Europe this is an important thing, and if you want to do business for the next ten years in Asia and North America it's important, and in the next fifteen or twenty in the rest of the world it is going to be important.... those are vague predictions but it is going to be something like that. And I think increasingly we will be using less material and we will be designing with the idea that there will be some value after our product has done it's thing.

TM So you are designing more for the service that the customer gets out of it, and the product becomes a critical part which needs to be reuseable as possible?

EC Well that's right. I think ideally in the long term customers may hardly own anything, except things like a shirt because it's personal and wears out, but they probably won't own their television sets, or their automobiles, or their telephones, or any of those things.

TM How does moving to a global market alter the design of your products?

EC There isn't a tendency to have major differences in designs. If you are making more or less the same thing in several places around the world you would like to have it be virtually identical because if there is a sudden increase in demand somewhere you want to be able to make it in whatever factory has some extra room to make some more product. So you don't want a product that you are making in China to be completely different from a product that you are making in Oklahoma. At the same time there are going to be some local differences because of local standards or, Europe has size standards for racks that are different from the United States and so you have these small distinctions, but there is increasing tendency as you make things all over to do it from a single basic design which might have some minor modifications here and there.

TM And how about environmental standards and environmental expectations for the different nations in which you're producing?

EC Well they do vary, but not nearly as much as they used to. If you are setting up a factory in Asia or the Middle East you will find that their people come to all the same meetings and it is no longer a situation where you have Corporations intending to approach things very differently in different parts of the world. At the same time there are differences in the local infrastructure: you may have a residue of some kind that can be handled perfectly well in England or Singapore that can't be handled as well in some other countries and this might mean a change of process a little to use a different chemical or in some way you have to respond to this difference in the local capabilities. But another part of it is that even if you don't have local regulations that encourage something or constrain something, if again you are trying to think ten or fifteen years out, you might say to yourself, 'Is there going to be a Superfund sort of thing in Thailand in fifteen years, and if so, how do we avoid fifteen years from now having a major liability?' because they have something that they don't have now, but the Superfund kind of thing that has been going in the United States for the past ten years all have 30 or 40 year histories, and if people in 1955 say, had thought hard about how something might be regulated in 1975 they probably would have done things differently.

TM *So how do you try and cope with that uncertainty?*

EC I would say that the major thing is to try to be very careful about the choice of materials and how you design the processes that you are using and so on. Certainly paying lots of attention to what things are regulated or otherwise things that are known not to be beneficial and are likely to be regulated. But also to pay attention to things that - and here's your link with the environmental scientists - demonstrate is not the best choice even though it is not constrained in any legal way at the moment.

TM *Do the designers actually realise that their product design decisions alter a great deal of the manufacturing processes? I suppose working in concurrent engineering teams I guess it gives them an opportunity to see exactly what they are doing in respect to everything else?*

EC Oh I think so. This is very different from the way it was say 10 or 15 years ago. The people are very much more likely to be 'living together' as these things develop and to say, 'If you make that decision this is what it is going to mean in manufacturing, and this is what it is going to mean in packaging, and this is what it is going to mean in installation'.

TM *And when you first switched to this team-working approach did that first of all set back the time a little bit as they got used to it?*

EC I don't think I know that that well, but that preceded probably by a couple of years our efforts in DFE so in some sense it was already happening....

TM *...you came into a team working environment?*

EC Pretty much. Although again in a large Corporation there is a lot of variance.

TM *And how well was that actually affected when you came onto your first design team, did they see you as being the DFE checkpoint police?*

EC I would say that once you convinced them that you are not going to have a strong negative impact on some of the other things they think about, then they are quite receptive. There is initial nervousness about what this might mean for cost, what this might mean for the time between design and manufacture.

TM *Is this again from middle management?*

EC I think that part is everybody. Everybody is concerned with, 'Can we save a Nickel here, can we save a week here?'. They are quite tightly constrained, and they are concerned about anything that could influence that.

TM *Your own introduction to them then would be a series of presentations to them?*

EC Often it would be yes.

TM *At anytime during the design process are you a conduit to the design team to environmental expertise? Do they actually use you to ring up and say, 'I have a problem with my design'?*

EC Yes, it can. I would say that doesn't happen too often, but there are a few people who have become real zealous, and they feel that they could well do that.

TM *Do you think that they drive the success of that in their design?*

EC In a way, yes. The real way this works is to have a zealous natured design team. So I guess one of the things that I try to do is instil zealouts!!

TM *OK. What other opportunities do they have to learn? I mean, if they really want to know more are there a series of routes they can go down to get information?*

EC Well it is one of the reasons that [my colleague] and I have been writing our DFE material for our engineers. They are used internally as well as externally in design and also we are finding that the professional societies the designers might belong to, it's likely for them to have related meetings, workshops and symposiums and so forth. The Mechanical Engineering Institute organise their own and so forth.

TM *They have their own methods of finding further information then?*

EC Yes, so soon they are getting a message like this from several directions, here and there, and it plays up differently with each person and they are all I hear.

TM *Are you happy with the way that they are progressing in terms of gaining an environmental approach and the environmental culture towards design?*

EC I am happy with the direction, I guess I could be happier with the speed! But that would be, that is an almost universal thing any way. So it is a big elephant to change direction on fast. It's going all right, it hasn't completely changed every person in every design team and I would like that, but....

TM *....you would like to be many people at the moment?*

EC Yes I guess. I mean, one of our people has dedicated about at least a third of her time, may be as much as half to really being an active participant in a design team for a new product. So she just goes in every meeting I have and every design activity she is part of it, and it would really be nice if we had somebody to do that with every design.

TM *Is that her job or is has she developed into doing it?*

EC I think originally it was her supervisor who said, 'Why don't we try and do this?'

And that has been, it's been successful but it is clearly something that we are just never going to have enough people to deal with every design team, and so we are trying to use that to take what we are learning from that and make that information a little bit more widely available. But there is nothing like having somebody sitting right next to you when an idea comes up, and they can comment on it.

TM *In terms of demonstration, you said that you gave them a lot of things that they could see right away, such as the target plots. Have you ever worked on a concept product with them? For example have you seen the Philips Green Television?*

EC No.

TM *Well what they basically did, they went along to a design team and they threw out time and cost, and said 'Let's just look at the design of a television, and if we had all the time in the world, and all the money in the world, how could we focus this environmentally?', and actually designed and manufactured about five of them just to demonstrate so they could let all the other design teams see what pit-falls they came across, what opportunities there were and at the end of the day you can have this touch-feel product on the desk. Have you done anything like that?*

EC No. I don't think so. We have tried to do what we have done within our existing product line. But that is an interesting idea too!

TM *It is a bit of a leap forwards, it is almost like a concept car, you can't actually drive it, but...*

EC Yes.

TM *If you were the CEO of the company what would you do differently in terms of environmental design?*

EC I think probably what I would do is try to figure out a way to get the attention of the middle managers on the issues. My perception isn't that we are short of tools, or short of enthusiasm in the design teams. I don't think we are short of the visions, but the implementation is always hard work and anything one can do to encourage that is probably going to make the biggest impact.

TM *Just finally now, I was reading in the paper, you had in the IEEE proceedings. You chose from a number of tools to use on this product design. How did you find that experience, because it is something that we are trying to do, to pick from a list or a group of tools and try this bit out, and try this here in the design process; what were your experiences of using different tools?*

EC I think the feeling would be that you need three types of tools. You need something that makes a very general assessment and so I think that means some version of Life Cycle Assessment, probably streamlined because that is going to be more feasible. You need a good technique for presenting the results of that, maybe not in their full detail, but at least the principle results to everybody you can think of: the design team; management; the other people in the Corporate staff. And you need some way to prioritise the recommendations, both because that is a help to the design team and because it shows them that you know that they have other concerns as well; it helps to validate your existence. Now given that you have those three pieces my suspicion is that exactly what those pieces are is probably not too important. If you look at what comes up in the IEEE symposia, and the IEE thing in Scotland a year or two ago and a few other places, you find Corporations coming up with what I would call variations on a theme. If I pour out a little bit I could find you five or six different matrix approaches to Life Cycle Assessment, some more complex than others, but my guess is that they all work about as well when it comes to what you are really trying to do and that is to get the designer to make a responsible decision. I don't think it matters whether you have a five by five matrix, or a three by eight. Dow's is quite large, Motorola's is done in stages, it probably doesn't matter too, much the important point is that you have got in with the design team, you are looking at a spectrum of concerns and you are making improvements on the product. So I don't, at this point at least, think we have a Holy Grail of tools, but we have a list of the sorts of characteristics that you need in order to work with those teams.

TM *And do you place those at different stages of the design process or do you just try to get them all in as early as possible?*

EC I would try and get them all in as early as possible because early on you want them to be thinking about, 'How much do materials matter? How much does taking it apart matter? How much does energy matter?' And the earlier you can just get them thinking along these general lines the more likely you are to have good outcomes at the end.

TM *Now in the future what would be the ideal level of intervention that you as an environmental expert group would have for the design team? Would you say they'd do a large part of it themselves or do you think there is always going to be the need to ring them up to remind them or knock on the door?*

EC Certainly the ideal would be that they do a large part of it themselves. I think I am sceptical that they are ever going to be able to do the entire job themselves because there are too many issues that are extremely difficult to reduce to the checklist sort of format, or if there's some kind of quantitative thing, you put in your materials and here's a number, you put in a new set of materials and it gives another number. There are some people that are doing that and I don't think it's a total failure but I know they miss things. For example, we don't really know what kind of a number to put on biodiversity. And if you look at the Eco-points scheme or the EPS system or a whole bunch of others, by and large they are missing that completely. That is the sort of thing where in a qualitative check-list sort of framework, you can play that off against some of the other concerns. 'Is energy more important than solvent use?', and all these things that really get a little more environmentally sophisticated. I suspect those will always be with us and we will always have to have some way in which design teams can link themselves more to the people who spend their lives trying to figure these things out.

TM *Yes.*

EC But, probably the first 60 or 70% of this is pretty straight forward and to the extent that we can move that very close to the design teams as a part of their everyday living, that's a reasonable goal.

TM *I think that concludes my questions. Thanks very much indeed. Is there anything that you wanted to ask of us?*

THE END ....

appendix 5

eco2 information

eco2-irn stands for: **eco**logically and **eco**nomically sound design and manufacture - **i**nterdisciplinary **r**esearch **n**etwork.

Called 'eco2' for short, the forum was set up in 1994 by the author as a focus group to discuss environmentally conscious design issues and ideas with a like-minded group of researchers. There are now over fifty members of this group, representing the UK, Holland, Germany, Sweden, and Australia. Ideas are shared by means of holding quarterly meetings and interim communication is enhanced by an internet discussion list.

Since 1994 the collaboration across universities in the area of environmentally conscious design has grown; many members of the forum are now taking part in joint authoring of papers and book chapters and helping each other to organise and host seminars and colloquia.

The following text is taken from the forum's web-page.

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eco2

Background

The eco2-irn forum was founded in 1994, when a group of like-minded researchers recognised the value of discussing their areas of research with each other, sharing ideas and problems, and stimulating new discussion for the furthering of knowledge in the area of environmentally conscious design and manufacture.

Our Mission

- To encourage the move to sustainable business practice by creating a forum for those concerned with research into environmentally conscious design and manufacture (ECDM).
- To discuss and exchange information and ideas about reducing the environmental impact of products, processes and services, at every stage in their lives.
- To enhance the quality and scope of our research by sharing ideas across a broad network of researchers, in the UK and elsewhere in the world.

Documented Forum Discussion Topics

- Environmental Best Practice - What Is It?
- Eco-Strategy: The Steps Towards Formulating An Environmental Policy For An Organisation
- What is Green Design?
- What Is Eco-Design?
- An Appraisal of Eco-labelling From A Design Perspective
- Telephone Disassembly Workshop
- Summary Of Environment-Related Acronyms Used Today - our definitions...
- Environmental Best Practice - What Is It?

- Integration of DFE Tools with Product Development
- How do we support DFE?
- Clean Design Research Needs (with visitors from the EPSRC and the Design Council)
- Design & Development Of An Eco-Efficient Kettle
- Textile Design & The Environment: towards an integrated approach to production and industry
- An Introduction To The National Centre for Business and Ecology (NCBE)
- The Formation of The Earth Centre

Web-site: http://www.zen.co.uk/cim.inst/research/environm/eco2-irn/intro.html