Eco-innovation:
tools to facilitate early-stage workshops

A thesis submitted for the degree of Doctor of Philosophy

By

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Preface

This research began in 1998 when I started work on a two-year research project in partnership with Loughborough University: 'Investigating step-change approaches to environmental improvement of electronic products' (Williams & Harrison, 1997). The aim of the project was: 'to develop life cycle models and methods to facilitate the conceptualisation and design of telecommunications products and product systems, which display non-incremental environmental improvements' (Harrison & Walsh, 2000). Outputs from the research team were diverse, ranging from an analytical framework for identifying the potential for radical environmental improvements (Low & Williams, 1999), to simplified environmental life cycle assessment approaches for consumer electronics products (McLaren et al., 1998).

From working on this collaborative project, I became interested in developing further tools and methods for step-change environmental improvements. I decided to continue my research as a fulltime PhD student and extended my work by two years to complete this research.

At the time of submission I have taken a position at Kinneir Dufort Product Design where my main activities are the facilitation of early-stage workshops and the development of design research services for our clients.

Acknowledgements

This research was carried out at in the department of design at Brunel University. I thoroughly enjoyed my time there and would like to thank all the academic staff, design support staff, and fellow researchers for creating such a friendly, supportive environment to work in. Thanks also go to the students who took part in the workshops held in May 2000 and June 2001.

Thanks go to my supervisors, professors Neville Stanton and David Harrison: Neville Stanton for introducing and sharing the joys of empirical research; David Harrison for taking me on as a research assistant in the first place, for allowing me the creative freedom to develop within the confines of the EPSRC project, and for continuing to support me as a PhD student.

Within the eco-design research community, thanks go to the members of the Eco2-IRN forum for being the expert judges in chapter 7 and for providing such an open and supportive network. Thanks to Andrew Sweatman for allowing me to publish early developments of the PIT diagram, which made use of some his unpublished materials.

Several people from the TRIZ community have generously contributed their knowledge and experience. Thanks go to Darrell Mann for always sharing his TRIZ expertise, the collaborative papers and for initially giving me a place on the TRIZ course for industrialists at Oxford Creativity. Thanks also to: Creax TRIZ innovation software; Kim Stevenson and her colleagues from Pragmatic Vision in Boston; Ellen Domb editor of the TRIZ journal; Ian Mitchell from Ilford Photographic; and Ian Care.

Thanks also to Rob Holdway from Giraffe Innovation Consultants for the stimulating exchanges on the use of tools and workshops.

Special thanks go to my husband Iwein for his continual support and encouragement, and to my parents for their extreme generosity and for always proof-reading chapters at short notice.

Abstract

This thesis presents research carried out into the use of creative tools at the early stages of eco-innovation. Eco-innovation is a practical approach aiming to develop new products and processes which significantly decrease our impact on the environment. Designers are trained to develop profitable products that increase production and consumption. Eco-innovation is a new discipline in which designers can radically reduce the environmental burdens of production and consumption through the innovation of new types of products and services.

The main aim of this research was to develop an approach that would promote significant environmental improvements whilst remaining a practical, design-focused discipline. Problems and under-investigated aspects of eco-innovation were identified:

- Creative approaches at early stages of eco-innovation were under-investigated and few tools had been developed for use at the early stages.
- Empirical design research techniques had rarely been used to assess new eco-innovation tools or to inform their subsequent development.

The focus of the research work was the development and testing of tools to facilitate workshops at the early stages of eco-innovation. Not only was the goal to facilitate the generation of radical ideas but also to ensure that these were developed into appropriate solutions having the potential to be taken up in industry. The development of the tools was based on literature research, worked examples and interviews. The tools were tested in controlled workshop experiments and the results were analysed using various empirical techniques.

First, an idea-recording technique to improve the efficiency of generating and harvesting ideas in a team design process was developed. This novel tool was called the Product Ideas Tree (PIT) diagram. The tool was tested for its ability to facilitate design workshops. Secondly, a structured approach to innovation - the theory of inventive problem solving (TRIZ) – was investigated. Worked examples using some of the tools from TRIZ were presented and a limited number of tools were selected and simplified

for testing in team design workshops. The PIT diagram and TRIZ tools experiments established which attributes of the tools and approaches were most beneficial.

The development and testing of these specific tools provided the following general contributions to eco-innovation:

- A model for eco-innovation that describes the factors influencing the discipline and the attributes of good practice.
- A recommended process to transform radical ideas into appropriate solutions to improve their potential to be taken up in industry.
- General insights into the use of tools in early-stage workshops such as: tool selection, integration into existing processes, system-level problem solving and providing thematic information.
- Suggested improvements for testing tools in controlled workshop experiments.

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Chapter 1 Introduction

This thesis develops eco-innovation as a practical design approach for the environmental impact reduction of products, processes and services. The work has explored, developed and tested tools and methods for the early stages of eco-innovation. This chapter introduces the study, the focus of the work and explains the thesis structure.

1.1 Eco-innovation in context

Eco-innovation is an innovative approach that has emerged from the environmental design discipline. In the 90's researchers discovered that most examples of environmental design consisted of incremental changes to existing products (Sherwin, 2000; Tischner & Charter 2001, O'Connor, Blythe & McEnvoy, 1998; Ryan, Hosken & Greens, 1992). As a consequence, there were calls for approaches which would provide greater moves – also referred to as step-change improvements – towards a more sustainable society. Eco-innovation is one of these approaches. Eco-innovation aims to develop new products and processes with significantly decreased environmental impact whilst still focusing on customer and business value (James, 1997).

In a recent publication, Tischner and Charter (2001) observe that businesses are starting to undertake the re-design of existing products for environmental impact reduction, but approaches to eco-innovation are still new to business. Eco-innovation needs further development to enhance the possibility of its take-up in industry and commerce. Much work is still to be done to provide tools and case studies for eco-innovation.

This thesis acknowledges the importance of the moves towards sustainable development through sustainable design, which integrates economic, environmental, social and ethical issues. Eco-innovation is a promising approach that *does* contribute to economic and environmental aspects of sustainable development. Social and ethical aspects, however, are considered outside the remit of eco-innovation.

Eco-innovation is chosen as the focus for this thesis because it promotes step-change whilst remaining a practical, design-focused discipline. When an over-arching term is needed to describe the entire field of research, the term 'environmental design' will be used throughout this thesis.

1.1.1 The Evolution of the Environmental Design Approach

Many authors have traced back the origins of environmental design in their introductions (Billett, Goggin & Walker, 1996; McAloone, 2000; Sherwin, 2000; Lewis & Gertsakis, 2001). This section places the contribution from this research in context by briefly laying out the evolution of environmental design approaches.

The pipe model

The pipe model shown in figure 1.1 below loosely represents industry and provides a simple structure to describe the evolution of environmental design disciplines. Generally, environmental design disciplines have evolved from end-of-pipe approaches towards approaches tackling issues at the front of that pipe.

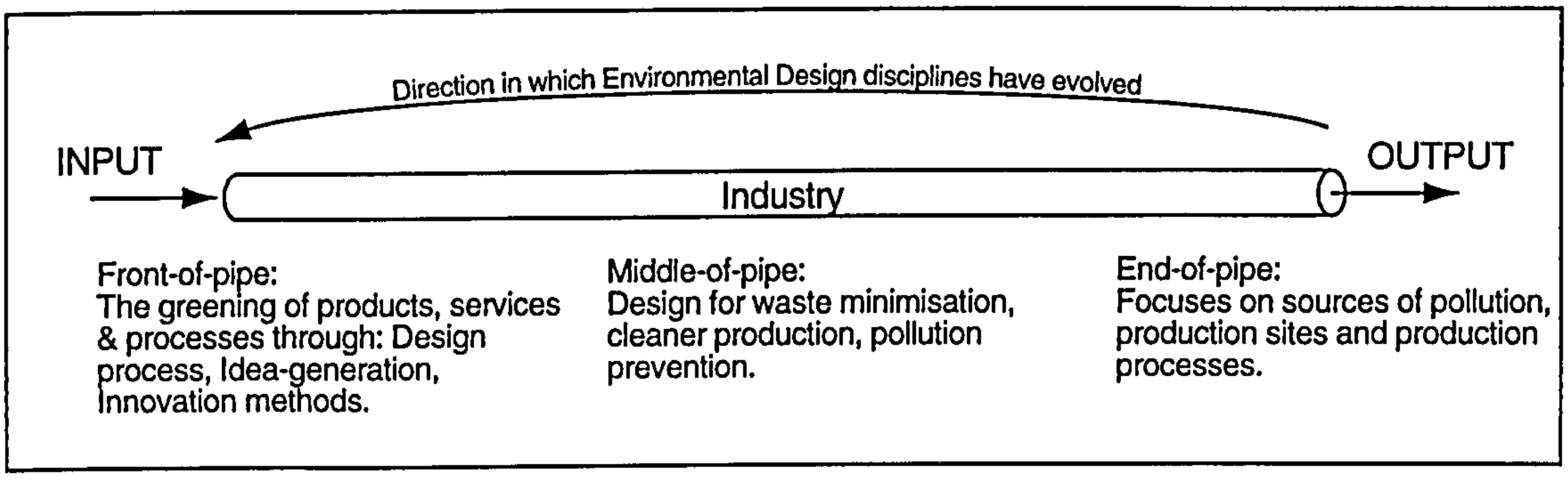


Figure 1.1: Pipe model describing the evolution of environmental design disciplines

End-of-Pipe

Initially, concern over pollution and waste led to approaches that 'block' pollution entering air, water or land. These approaches 'clean up' waste and focus on sources of pollution, production sites and production processes. Examples of such end-of-pipe approaches are widely seen in today's legislation and industrial standards: the 'polluter pays' principle, regulated emission standards, clean air and water quality acts, toxic substances control acts, controlled waste disposal, re-use of production waste, etc.

Middle-of-Pipe

From the end-of-pipe, new approaches evolved driven by an interest in waste *prevention* and pollution minimisation. Most efforts were focused on 'cleaner production': changing production processes to minimise resource consumption and waste in industry. Examples of these approaches are: design for disassembly, design for recycling, selection of alternative materials, and internal re-use of production waste.

Front-of-Pipe

The increased use of life cycle analysis (LCA) tools, and results from those LCA-studies, showed that the main impacts of products were often not the production processes themselves but linked to other stages of the product life cycle: the product's use or its distribution for example. This, combined with the consumer demand for 'greener' products meant that industry started focusing their environmental efforts on the products themselves. These approaches aim to improve the environmental performance of products throughout their lifecycle and the importance of design has become generally accepted (discussed further in section 2.2.1). Examples of these approaches are: the development of new product concepts, design for efficient distribution, design for optimum lifetime, and design for minimal consumption.

These front-of-pipe approaches all affect the design processes, idea-generation and innovation methods employed. This thesis contributes to these front-of-pipe approaches and looks specifically at those approaches that may provide step-change environmental improvements.

1.1.2 Step-change environmental design

Step-change environmental improvements are required to move towards more sustainable production and consumption modes. Increasing legislative pressures and consumer awareness of environmentally efficient products are causing businesses to look at environmental design as an opportunity to improve their products and processes (Meinders, 1999; Stevels, 2000; Nokia, 2000). Business, government and academia have identified a need for strategic approaches in product, process and service design that will result in the step-change environmental improvements (Fussler & James, 1996; Berkhout & Smith, 1998; Lewis & Gertsakis, 2001; Sherwin et al., 1998).

Defining step-change

Step-change environmental improvements are also referred to as leap-change or factor–change environmental improvements. Most examples from industry show that environmental performance is normally improved through incremental-change as opposed to step-change. Due to global population growth and the overall increase in consumption these incremental improvement steps will not sufficiently reduce the overall impact on the environment (Von Weiszacker, Lovins & Lovins, 1997; Billett, 1998).

The terms step-change, leap-change or factor–change have emerged to describe approaches that go beyond the incremental approaches seen in environmental practice today. These approaches set out to create more significant improvements in environmental performance.

The need for step-change

The trends in population growth have been measured and widely commented on in recent times (Ehlrich & Ehlrich, 1972). Until recently, global population growth was exponential, which meant that there was little hope for sustainable development. In 1998 the United Nations published their world population projections in which they predicted a stabilised world population for the first time (United Nations, 2000). Theoretical models to calculate sustainable development at certain population sizes have been developed. With a stabilised world population, such calculations become more relevant and can describe the magnitude of reductions in resource consumption necessary to achieve sustainability. Figures have varied between authors, depending mainly on the assumptions made about the wealth and resource distribution across the world. Some estimate that a 90% - or factor 10 - reduction of current levels of resource consumption is necessary to achieve sustainable development (Schmidt-Bleek, 1994), whereas, for example Von Weiszacker, Lovins and Lovins (1997) propose a 75% (or factor 4) reduction to stabilise the climate.

Harrison and Pearce (2000) have looked at various consumption indicators from the 60's onwards and concluded that the growth of consumption has been even greater than the population growth. Average world income per person continues to grow, placing increasing demands on the world's resources. In the developed world the number of individual households has also grown, and smaller dwelling units have significantly higher consumption rates per person. Surveys also show how consumer attitudes rapidly shift, whereby yesterday's luxuries become today's necessities.

Several authors highlight the need for 'breakthrough innovation' (Fussler & James, 1996), 'quantum innovation' (Billett, 1998) or 'leapfrogging technologies' (Chiodo, Ramsey & Simpson, 1997) in order to achieve the necessary step-change improvements in environmental impact leading towards sustainable development.

Models of step change

In 1996 Brezet, Cramer and Stevels (Brezet, 1997; Stevels, 1999) described a model, hereafter referred to as the BCS-model, for step-change towards sustainability. The BCS-model describes four levels of environmental innovation. Brezet (1997) describes these four levels as s-curves on a graph where the x-axis represents time - how far into the future each type of innovation would be expected - and the y-axis represents the level of eco-efficiency aimed for. The curves shown in figure 1.2 describe four possible levels of environmental design activity: product improvements, product redesign, function innovation, and system innovation. These levels are used by Stevels (1996) to describe the involvement and investment required in an industrial setting.

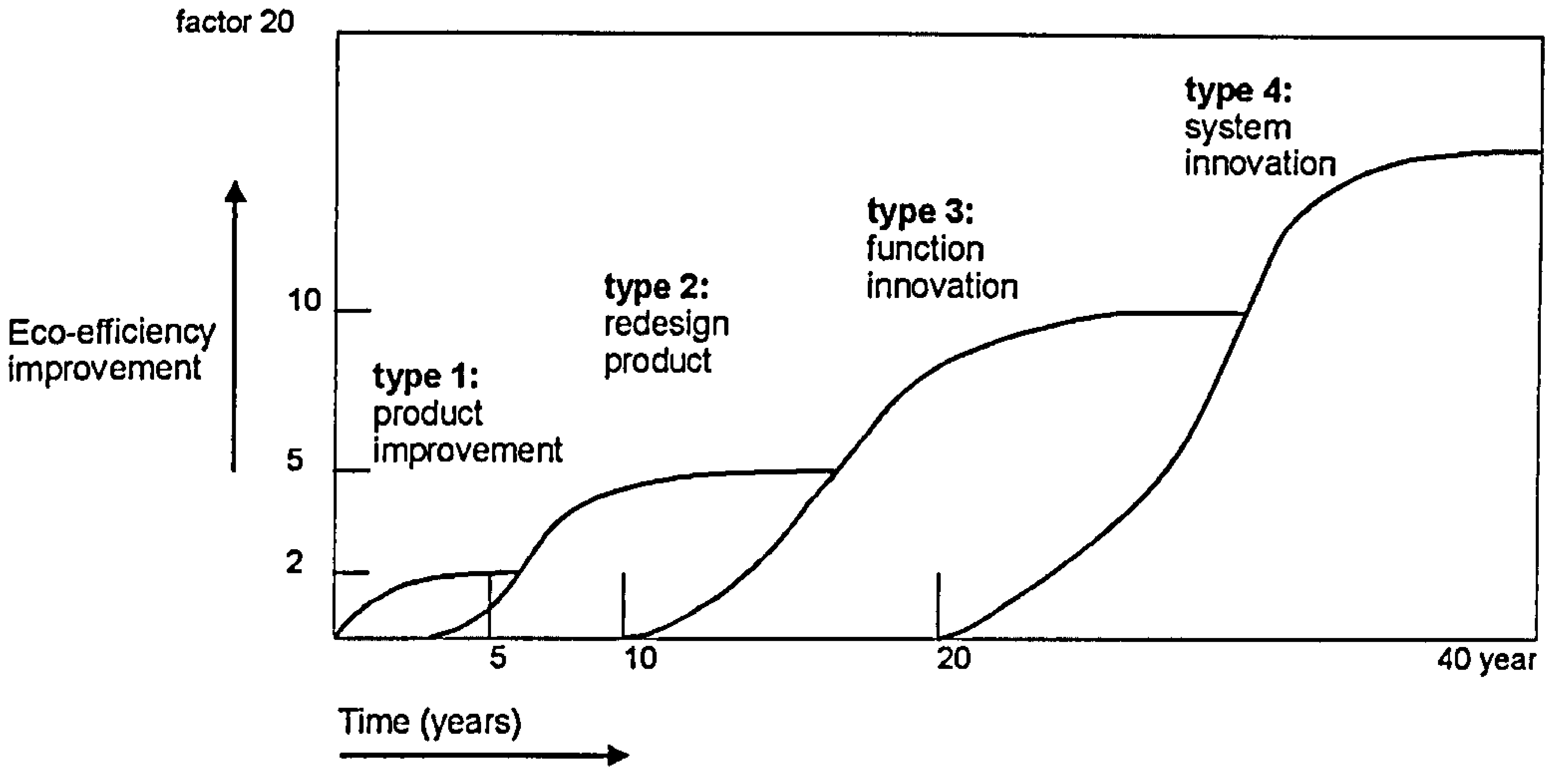


Figure 1.2: BCS-model, four types of ecodesign innovation after Brezet (1997)

This model was used in the initial stages of this research to gain an understanding of the terminology and practice of environmental innovation. One of the first outputs from this research was an overview showing the types of products and product concepts from the telecommunications sector organised according to the BCS four-step model. That overview can be viewed in appendix 1.

The Centre for Sustainable Design (Charter & Chick, 1997) developed a model describing the development of approaches towards environmental protection which was similar to the BCS four-step model. The four strategies they named were: Re-pair, Re-fine, Re-design and Re-think. Again, these approaches were described as curves on a graph where the x-axis represents time and the y-axis represents the extent of the environmental benefits. Their 'four-R' model shown in figure 1.3 is used to describe and promote the stages that companies and designers need to move through to achieve greater step-changes in environmental benefits. More recently, this model has been used to describe the conditions required in industry to achieve the moves through these stages (Tischner & Charter, 2001).

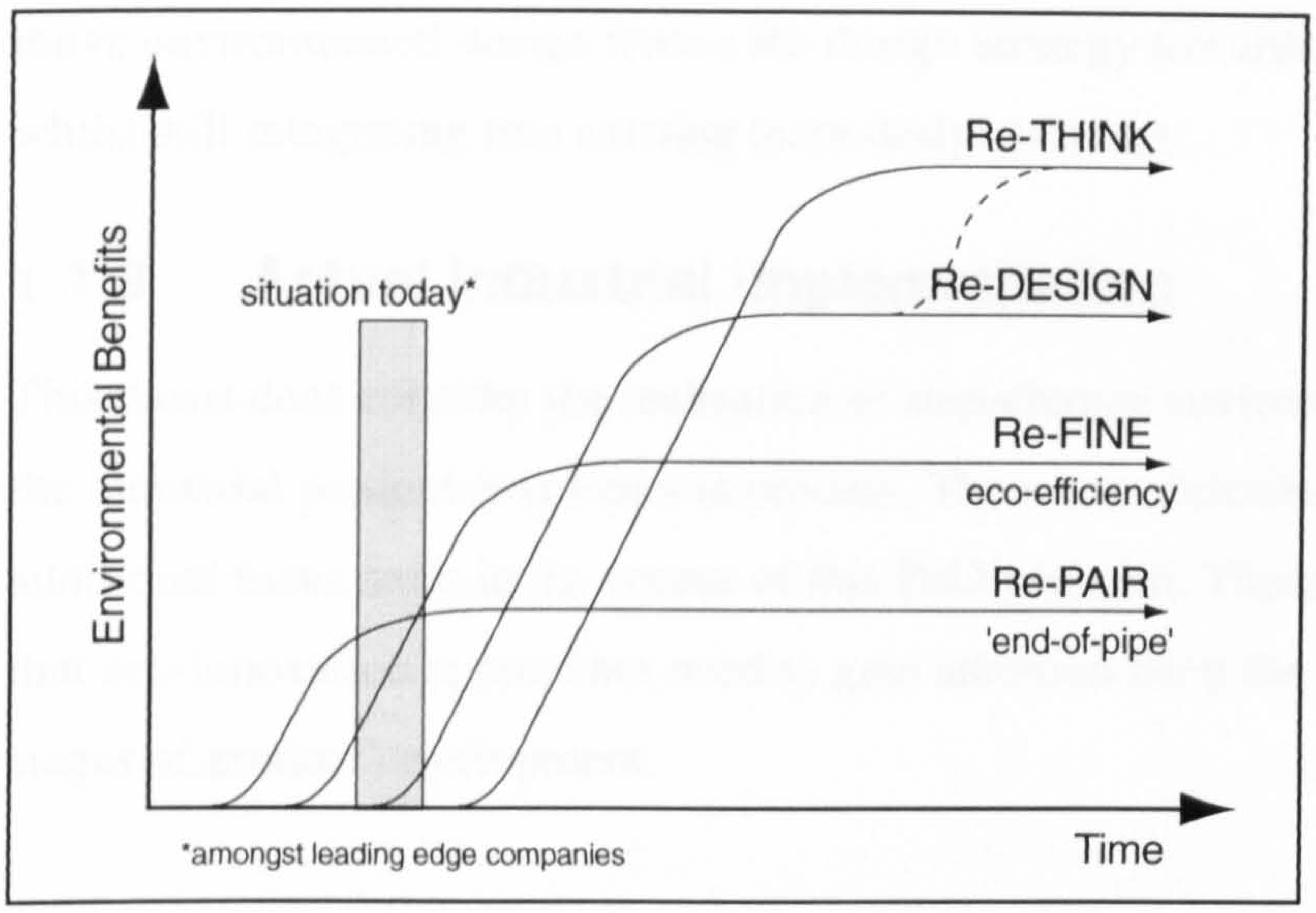


Figure 1.3: 'four-R' model after Charter & Chick, 1997

Achieving step-change

Lamvik (2001) looks at step change in a business context and stresses the importance of a fundamental shift in focus. He states that step change improvement of environmental performance can only be achieved by increases in the 'service efficiency' of the given material stock. The solution he offers is based on the principle that industry must focus on the service or the function delivered by their products and then optimise the delivery of that service or function. This approach will reduce the material throughput of the economy without losses in overall consumption. These step-changes cannot be achieved overnight, because they will require changes in current business practices, and because they involve adapting the way products are manufactured and supplied.

Van Den Hoed (1997) stresses the need for a fundamental shift in environmental design. He summarises his research on 'breaking the incremental character of ecodesign' by describing the transition that is to be made from incremental eco-design to sustainable innovation as three shifts in focus: from product optimisation to functional innovation; from product-level to system-level; from product design process to innovation process. His work is reviewed in more detail in section 1.2.1.

This thesis makes a contribution to breaking the incremental character of environmental design by developing eco-innovation further. The tools and methods proposed aim to move environmental design from a Re-design strategy towards a Re-think strategy, whilst still integrating into existing team design practice.

1.1.3 Actual industrial implementation

This thesis does consider the realisation of step-change environmental improvements in the industrial product development process. The issues described below are some of the additional focus areas in the course of this PhD-research. These issues highlight the fact that eco-innovation approaches need to gain attention from the right people at the right stages of product development.

Creative approaches at early stages

Previous design research has shown that about 70-80% of a product's features and costs are determined at the early stages of the design process (Andreasen & Hein, 1987). Tischner and Charter (2001) deduce that the environmental impact of a product must therefore also be determined to a large degree at the early stages of the design process. Many authors have stated that integrating design-led environmental approaches at the earliest stages of product development is critical to their environmental effectiveness and their ability to innovate (Van Den Hoed, 1997; Matzke, Corky Chew & Wu, 1998; Van Nes & Cramer, 1997). Other authors have highlighted the need for more creative approaches to integrate environmental earlier into a company's product development processes (Tischner & Charter, 2001; Lewis & Gertsakis, 2001; Chiodo, Ramsey & Simpson, 1997; O'Connor, Blythe & McEnvoy, 1998; Simon et al., 1998). The early design stages *have* been identified as crucial, but very *few* environmental design tools or methods have been developed for use at these stages (Bhamra et al., 1999; McAloone, 2000).

Some discussions have focused on the integration of environmental issues and concerns at *different* stages in the product development processes (Charter, 1999; Sweatman & Simon, 1996a; Simon et al., 1998; Tischner, 2001), but creative approaches at *early* stages of the design process have been identified as under-investigated (Bhamra, et al. 1999; McAloone, 2000). This research therefore focuses on the early stages of the product development process.

Take up of tools and methods

Several PhD researchers have conducted substantial reviews of environmental design practice in different industries (De Bakker, 2001; McAloone, 2000; Van Hemel, 1998). Some researchers that have conducted such industrial reviews have concluded with the proposal of a new 'Design for Environment' tool or process (O'Connor, 2000; Holloway, 1997). However, the industrial adoption of such new environmental design tools and processes is not widespread.

This problem of adopting new design tools is not exclusive to environmental design but a more general phenomenon; some of the generic barriers to adoption of new tools and processes, have been investigated. For example, some tools over-formalise existing or common sense techniques or are too systematic to fit in to existing design practice (Cross, 1994). Tool developers are beginning to adjust their approaches by taking the industrial climate into account more. Some authors are developing or advocating simplified versions of existing tools (Slocum & Lundberg, 2002; PDMA, 1996). Other authors consider industrial wishes and demands from the outset (Lofthouse, 2002; Stappers, Keller & Hoeben, 2000). For example, Stappers, Keller and Hoeben (2000) have studied the industrial context and have been developing 'tiny' tools: non-intrusive tools that can be more flexibly integrated into existing design practice across different industries.

This thesis recognises the problems that are inherent in introducing new tools and methods and aims to develop and test tools that can be non-intrusively integrated in existing practices across industries. In order to be suitable for different disciplines and industries the tools will have to be based on a design process that is generic. In order to be flexibly integrated in existing practice the tools will have to be open for interpretation and adaptation by the users.

Testing proposed methods

Significant contributions have been made to the field of creative environmental design without quantitative analysis of proposed tools and methods (Sherwin, 2000; Benjamin, 1994). In mainstream design research, however, quantitative research methods to analyse the design activity have been developing and increasingly adopted over the last three decades. There are two main ways of using empirical research to inform the development of tools and methods. The first is a very theoretical approach: existing design practice is studied empirically, problems are identified, and tools or methodologies are suggested based on firm research findings. The second approach is an iterative development process in which: tools and methods are first suggested, subsequently tested using empirical research, upon which improvements are suggested.

This research is based on the latter, iterative development process. The tools and methods are suggested and tested based on a simple model for eco-innovation introduced in section 1.2.2.

1.1.4 Research Boundaries

This section gives short explanations of some important terms that will be used throughout this thesis. These definitions help describe the boundaries of the research.

Product, process or service design

This research aims to be relevant to designers and other participants from different disciplines and industries. The word 'design' in this thesis covers all the activities that take place to get a product to market. Due to the worked examples and workshops conducted for this thesis, the work is likely to be most relevant to product designers, industrial designers and engineering designers. However, these designers are active across a spectrum of different industries and may be involved in designing tangible products, industrial processes or less tangible services, software and interfaces. The word 'product' is used in this thesis as an umbrella term to describe all the different types of projects that these designers might be involved in.

System Level

In order to move towards step-change environmental design authors are calling for system-level innovation, strategic approaches or more conceptual design. These calls all emphasize the shift in focus required away from a product-focused design activity. This research has found hierarchical models of design useful (Lawson, 1990; Tjalve, 1979) and recognises the important contribution that systems thinking has made to design and problem solving in today's complex industrial situations. (Checkland, 1981; Wilson, 1990)

Several of the research contributions in this thesis include hierarchical models in which different system levels are defined. The term 'system level' is used in this thesis to describe a level *up* the system hierarchy from the 'product level'. 'System level' is a relative term and can represent different things in each practical case. It generally refers to work at a more strategic or conceptual level *above* the product focused design activity.

Stakeholders

Product stakeholders are all the different people who are affected by, and influence a product throughout its life cycle, such as: product users, distributors, service and asset managers. Stakeholders can influence the product's environmental impact and therefore should be involved in the product development process (O'Connor, Blythe and McEnvoy, 1998)

Quist and Vergragt (2000) state that any type of 'system innovation' takes place in a multi-actor, multi-disciplinary context with stakeholders from different societal groups. Design research has shown that to create innovative products the integration of different specialists has become a crucial part of the design process. These specialists are affected by the context in which they work and build on their past experiences (Sonnenwald, 1996). The stakeholders have different interests, aims, knowledge values, views, opinions and perceptions which makes stakeholder collaboration a crucial factor for success but also a tricky issue for the environmental design discipline.

Practical environmental design research has begun to take a closer look at stakeholder collaboration (Quist, Vergragt & Young, 1999; Vergragt et al., 1995; Street, 1997). This thesis acknowledges the importance of stakeholder collaboration but has conducted research within more conventional design teams.

1.2 Theories and models of Eco-innovation

Having defined eco-innovation and provided some context for the approach, this section gives an overview of research perspectives on eco-innovation and provides a simple model for eco-innovation. A number of important references are reviewed. These references inform the model for eco-innovation which forms the framework for this research. This model for eco-innovation is introduced and its role in this thesis is explained in section 1.2.2.

1.2.1 Perspectives on Eco-innovation

Towards sustainable innovations

Van Den Hoed (1997) reviewed the work of six major contributors to visions on 'sustainable innovations' and conducted a pilot study. The term 'sustainable innovation' equates to the term eco-innovation used in this thesis. He concludes that there are three essential aspects of sustainable innovation:

- Function as the starting point;
- System-level innovation;
- The use of an innovation process.

He made observations and identified knowledge gaps on those three aspects; each of these will be considered in turn.

The authors he reviewed all suggest that the product development process should start with the functions that the product is to perform or the consumers' needs that are to be fulfilled. However, in current literature no descriptions are given on how to perform such function- or needs-oriented design. If companies develop new products with function as the starting point, cost-reduction will no longer be their financial driver and they may have to venture into completely new markets.

The authors he reviewed all describe a systems approach to innovation where changes are made beyond the product level. However, the broader the system is defined, the more different stakeholders will have to be involved in the development. Companies attempting to conduct system-level innovation will find that environmental design lacks the methods and tools to define a system effectively, and that environmental validation methods able to operate on the system-level are yet to be developed.

He suggests that sustainable innovation would benefit from research into the theories from mainstream innovation management, system analysis and functional assessment. If environmental aspects are to be integrated in an innovation process, more strategic managers and planners will need to be involved and the typical time frame for the process will be extended.

Van Den Hoed's work provided an excellent starting point for this thesis. All three aspects have been included in the model for eco-innovation shown in figure 1.4. His suggestion to include mainstream innovation management falls under the first factor which influences eco-innovation: design and innovation practice. His two other conclusions have informed two of the attributes of successful outcomes from eco-innovation practice: the outcomes should be a new way of fulfilling the needs or function required (original) and should tackle problems at higher system levels (system level).

Environmental payback

Beard and Hartmann (1999) stress the idea that eco-innovation is about moving away from the reactive, negativist approach of 'impact reduction' to a more positivist approach about stimulating new ideas through higher levels of creativity and innovation. Businesses must move beyond confrontation and compliance, towards becoming a strong, positive, environmental force. Their definition of eco-innovation includes the principle of environmental payback or *e+*, where the design of products not only reduces natural resource consumption but even creates an environmental contribution, or 'payback' to the current resource stock. However, they do not give examples of products which demonstrate the *e+* principle well. They stress that people are the main drivers for eco-innovation and a creative and innovative culture in business is required to make eco-innovation possible.

From their work this thesis took on the objective to stimulate creativity and innovation. They highlighted the importance of the individuals involved in each project. This aspect has been included in the model for eco-innovation (figure 1.4) under the third factor which influences eco-innovation: the participants' experience and perspectives.

Contributions from mainstream innovation theory and practice

The term mainstream is used throughout this thesis to describe design and innovation tools or research from *outside* the specialist environmental design field. The term does not say anything about how common or widely used those tools or theories are. Mainstream innovation research sees an increasing number of structured innovation methods to help reduce the associated risks and lead-times. Most of these methods have not been investigated for their potential to contribute to environmental innovation. There are however some exceptions which are outlined below.

The work conducted by Van Der Horst, Vergragt and Silvester (1999) combined mainstream and experimental evaluation tools to support their 'sustainable roadmapping' process. Their conclusions highlighted the need for more investigations of the use of such mainstream tools and methods in eco-innovation.

Johanssson and Magnusson (1998) explored several innovation theories from mainstream practice in relation to eco-innovation. They describe two eco-innovation exemplar cases using S-curve models and transilience maps from mainstream practice. The S-curve theory is useful as the curves describe the step-changes that are desired in eco-innovation. The transilience map is useful as it links crucial aspects of innovation: marketing and technology. They conclude that mainstream innovation theory is useful when analysing eco-innovation but will not necessarily help us understand *all* aspects of eco-innovation.

Roy (1994) explores a mainstream innovation theory to assess the evolution of five environmental product examples. Successful products, technologies and industries will evolve through the following stages: exploration, consolidation, maturity, re-innovation and decline. He concludes that most environmental products are still in the exploration stage and the more evolved examples are often those resulting from incremental redesign of existing products. Finally, he assesses which external factors (or drivers) affect the rate and extent of the evolution of those five product types and shows how these drivers of environmental design are interrelated. These product reviews provide case studies and the methodology is similar to the initial explorations into TRIZ for eco-innovation, reported in Chapter 6.

These researchers have all started to look at mainstream innovation theories and practice which can contribute to eco-innovation. Some of these authors have gone further and tried out some of the tools and methods from mainstream innovation. Tools and methods have been included in the model for eco-innovation (figure 1.4) as an important factor which influences eco-innovation. These reviews have also highlighted the relevance of contributing case studies in eco-innovation. Case studies help to build a body of knowledge for the practical implementation of this new approach. Parts of this thesis contribute case studies to the body of eco-innovation knowledge.

Business focus

Fussler and James (1996) use eco-innovation in the title of their book, which presents a tool and case studies of eco-efficient products and services. Eco-efficient products and services are environmentally efficient *and* economically profitable. They use the term eco-innovation to describe their 'breakthrough discipline' for innovation *and* sustainability. Their work has a strong business focus and tackles issues such as: innovation lethargy, value creation, markets, profits and business growth, within the context of sustainable development. The aspect of their work most quoted is the tool they developed to make streamlined LCA useful for business decision-making. This tool, the eco-compass, is reviewed in more detail in Chapters 3 and 6.

The definition of eco-innovation adopted in this thesis is based on their work. Their business focus forms an important attribute included in the simple model for eco-innovation shown in figure 1.4: the outcomes should have the potential to be taken up by business (appropriate).

1.2.2 Towards a model for eco-innovation

This section introduces a model for eco-innovation which forms the framework for this research. This role of this model - shown in figure 1.4 - is explained in the thesis.

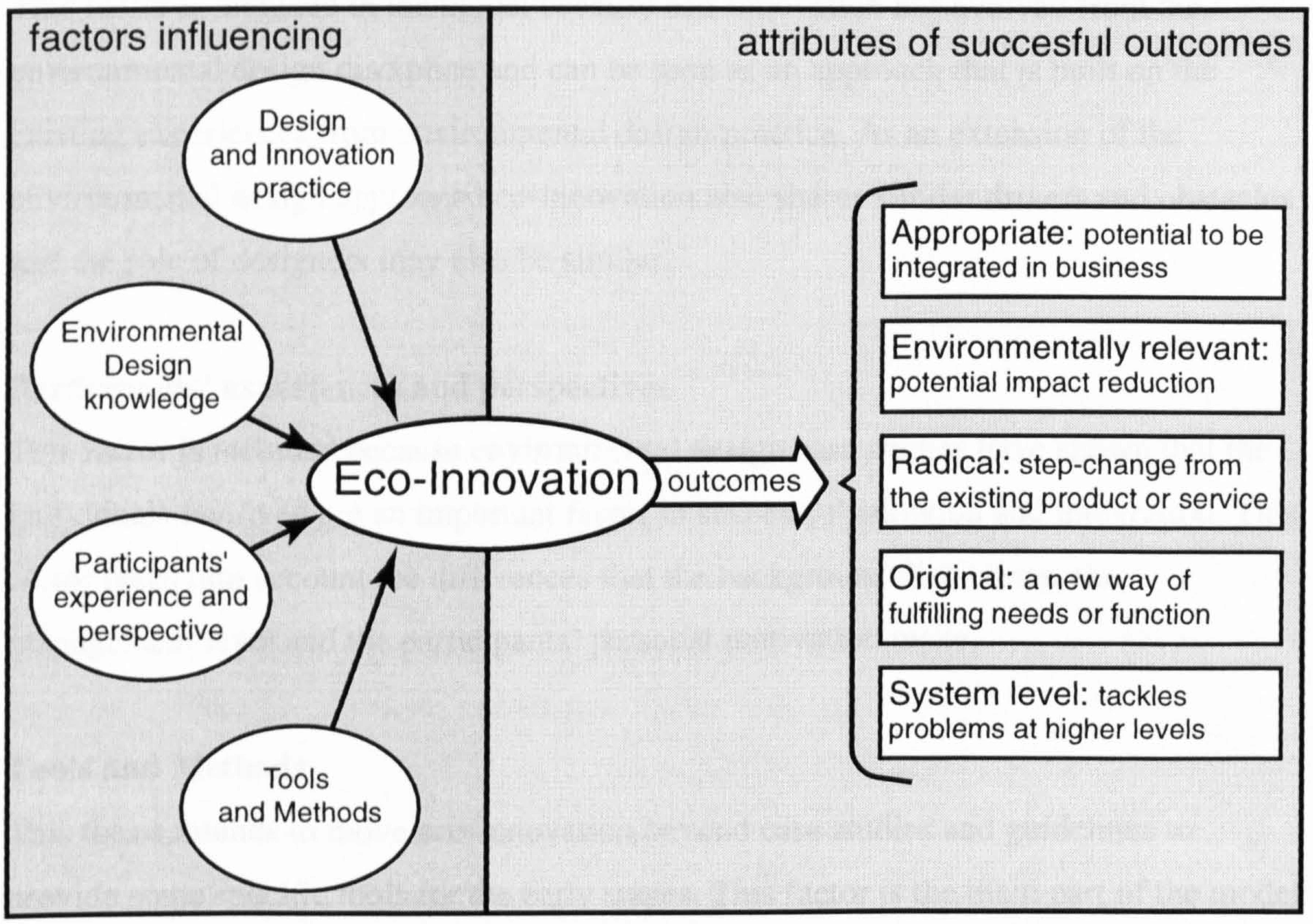


Figure 1.4: A model for eco-innovation

On the left-hand-side of the model are the four main factors that influence the practice of eco-innovation. On the right hand side are the attributes of outcomes from successful eco-innovation. The attributes provide a rich definition what practical eco-innovation is. Both the attributes and the factors are informed by the studies conducted throughout the thesis; only brief explanations are included below.

Design and innovation practice

Eco-innovation can be seen as a discipline in its own right or an extension of existing design and innovation processes with an additional environmental factor. In this thesis eco-innovation is the specific approach under investigation and therefore at the centre of attention and the model. Eco-innovation in this case is treated as a discipline in its own right which draws on the knowledge and theories of design and innovation practice. The model facilitates the discussion of this research contribution.

Environmental design knowledge

This factor is included in the model because eco-innovation has evolved from the environmental design discipline and can be seen as an approach that is built on the existing experiences from environmental design practice. As an extension of the environmental design approach eco-innovation also shares similar drivers and obstacles and the role of designers may also be similar.

Participants' experiences and perspectives

This factor is included because environmental design case studies have shown that the individuals involved are an important factor in successful adoption and integration. This factor takes into account the differences that the background disciplines, the management level and the participants' personal motivation make.

Tools and Methods

This thesis intends to move eco-innovation beyond case studies and guidelines to provide some specific tools for the early stages. This factor is the main part of the model under investigation. The new tools and methods proposed in this thesis are empirically tested using this model for eco-innovation and suggestions for improvements are made.

Appropriate

This is the first of the attributes of successful outcomes from eco-innovation: the outcome must have the potential to be integrated in business. It is an important attribute because if none of the concepts from an eco-innovation process become real products, processes or services, eco-innovation will not be contributing to environmental impact reduction.

Environmentally Relevant

The outcomes from eco-innovation must have the potential to contribute to environmental impact reduction. This criterion is not broken down into specific environmental attributes to be measured. This measure has deliberately been kept non-specific to reduce the effect of the extra environmental constraint that has tended to lead to incremental outcomes. This measure is intended to provide the freedom required to move away from incremental environmental design towards a process driven more by innovation.

Radical

The radical measure says that the outcome must represent a step-change rather than an incremental change to the existing product. As discussed in section 1.1.2, eco-innovation emerged as an approach to address the calls for step-change environmental improvements. This radical attribute acknowledges the importance of an innovative approach to environmental impact reduction of products, processes and services.

Original

The outcomes from eco-innovation must provide a new way of fulfilling needs or functions. This definition of originality is linked to the recommendations made for a new approach in environmental design which considers the needs or functions that the product, process or service is going fulfil.

System level

The outcomes from eco-innovation must show evidence of tackling problems at higher levels of the system's hierarchy. Tackling problems at higher system levels has been proposed as one of the design strategies for eco-innovation. One of the reasons for including this measure is to crosscheck whether this strategy results in successful outcomes.

The model presented forms the framework for this thesis. The 'factors influencing' are treated as independent variables and this contribution to eco-innovation is based on the investigation of these variables. Each chapter investigates different aspects of these variables. In some chapters these variables have been manipulated or controlled in order to focus this study on the development of new tools and methods for the early stages of eco-innovation.

The 'attributes of successful outcomes' are treated as the dependent variables that measure the success of the tools and methods proposed. These attributes have been distilled from the literature reviewed in this chapter but are also confirmed as valid measures and enriched by the studies conducted in chapters 4, 5 and 6. Chapter 7 tests proposed tools but also provides several insights into the attributes as measures of successful eco-innovation.

In the final chapter of this thesis (chapter 8) an extended version of this model is used to provide an overview of the different aspects of the independent variables that have been investigated in each chapter. This model also provides a framework for the discussion of the various contributions that have been made to eco-innovation.

1.3 Problem statement

Eco-innovation is the focus for this study because it promotes step-change whilst remaining a practical, design-focused discipline. Creative approaches at early stages of eco-innovation process have been identified as under-investigated. Very few environmental design tools or methods have been developed for use at these stages. Eco-innovation lacks tools that can be non-intrusively integrated in existing practices across industries. Mainstream innovation methods have not previously been investigated for their potential to generate radical environmental ideas which also have the potential to be taken up in industry. Empirical design research techniques have rarely informed the development of tools and methods for environmental improvements.

1.4 Research objectives

The central aim of this research is to develop practical tools or structured methods that can improve the early stages of eco-innovation. The tools aim to move environmental design beyond incremental improvements but should integrate into existing team design practice. The tools should facilitate the generation of radical environmental ideas and help develop them into appropriate solutions that have the potential to be taken up in industry. The tools will be developed using an iterative process based on empirical research.

1.5 Research contributions

First, an idea recording technique to improve the efficiency of generating and harvesting ideas at early stages of the team design process was developed. This novel tool was called the Product Ideas Tree (PIT) diagram. The tool was tested for its ability to facilitate the generation of environmental ideas in design workshops. The experiment established which attributes of the tool were most beneficial in the workshop session. Suggestions were made for its further development and conclusions were drawn on aspects of the testing process.

The second focus for research was the investigation of existing structured methods which had potential to develop more appropriate solutions that are more likely to be taken through to implementation. One structured method, the theory of inventive problem solving (TRIZ), was selected for further investigation. A number of worked examples that try out some of the tools from TRIZ are presented. Subsequently, a limited number of tools were selected and simplified for testing in team design workshops. The experiment established the extent to which the simplified TRIZ tools were beneficial in the workshop session. Some interesting findings on the criteria –or attributes – of good eco-innovation practice were also revealed. Suggestions were made on the use of TRIZ for eco-innovation and conclusions were drawn on aspects of the testing process.

The research contributions are all based on literature research, worked examples, interviews and controlled workshop experiments. Descriptions of the research methodologies are integrated in the relevant chapters.

1.6 Thesis structure

The main body of this research is the development of two novel tools for eco-innovation - the PIT diagram (Chapter 3) and TRIZ for eco-innovation (Chapter 6) - and their testing (Chapters 4 and 7 respectively).

Introduction

Chapter 1 describes the context - background research and topics of interest - which formed the point of departure for this research. This chapter explains the route taken in this research journey and highlights: the problems tackled, specific aims and research contributions.

Literature Review Eco-innovation

Chapter 2 provides a general background on environmental design and specific perspectives on eco-innovation. The research focus - on design workshops for eco-innovation - is established and statements are made about the tools to be developed. A closer look is taken at existing tools for environmental design and case studies that include early-stage workshops.

Development of the PIT diagram

Chapter 3 describes the development of the PIT diagram as it occurred: its evolution from an evaluation tool to a recording tool. The PIT diagram was based on an evaluation form – the Standard Design Process Form - and first used to review the output from a previous eco-innovation workshop. An opportunity was identified to develop the PIT diagram further as a recording tool to improve ideas capture in workshops. The initial use of the PIT diagram is reported and instructions for its use are proposed.

Testing the PIT diagram

Chapter 4 reports on the controlled workshop experiment that was conducted to test three aspects of the PIT diagram. A combination of different research techniques were employed to establish which attributes of the PIT diagram were most beneficial in the workshop session. The experiment provides ideas for further development of the PIT diagram as well as insights into better ways of testing such a tool.

Structured Innovation methods

Chapter 5 reviews the management of design and innovation, and tools from mainstream practice. Structured innovation methods are investigated for their potential to support innovation practice and design process activities. The tools sought should help translate ideas from an enlarged solution space –potentially created by the PIT diagram - into appropriate solutions that are more likely to be taken through to implementation. TRIZ is selected as a promising approach warranting further investigation.

Exploring the use of TRIZ in Eco-innovation

Chapter 6 presents theoretical and practical studies to assess TRIZ's ability to improve eco-innovation. A compact overview of the TRIZ methodology is given and theories that inherently support eco-innovation are highlighted. Further studies establish that TRIZ tools need not be adapted, provided environmental aspects are included in the system to be designed and problems are solved at high levels of that system's hierarchy. Popular TRIZ tools are selected for testing in eco-innovation workshops.

Testing of TRIZ tools in an eco-innovation workshop

Chapter 7 reports on the controlled workshop experiment that was conducted to test the three TRIZ tools selected. The tools are simplified for use in early-stage workshops. A combination of different quantitative and qualitative data is used to assess the process and the final outcomes. Conclusions are drawn on the use of these TRIZ tools in early stage eco-innovation workshops as well as on the criteria –or attributes – used to judge good eco-innovation practice. Suggestions are made on the use of TRIZ for eco-innovation and further insights were gained into aspects of the tools testing process.

Discussion and Conclusions

Chapter 8 brings together the outcomes from the research, presents the research conclusions and relates them to the aims set out in this study. An extended version of the simple model for eco-innovation is used to summarise the studies conducted and provides a framework for the discussion of the various contributions that have been made to eco-innovation. Finally, suggestions for further work are made.

Chapter 2 Literature Review for Eco-innovation

The central aim of this research is to develop practical tools or structured methods that can improve the early stages of eco-innovation. This chapter provides a brief review of the terminology and the drivers and obstacles of environmental design. A closer look is taken at tools for environmental design and case studies that include early-stage workshops.

First, an overview of the evolving terminology in environmental design is given, and the term eco-innovation is placed within one of the terminology models. The discussion of drivers for and obstacles to environmental design provides a link between the industrial and academic contexts for this research contribution.

Collections of tools for environmental design are reviewed and statements are made about the tools and methods to be developed in this research. Having established the research focus on workshop-style activities within the environmental design process, a collection of case studies that have included workshop activities are reviewed and conclusions are drawn.

2.1 Review of Terminology

The incorporation of environmental considerations into design, known as environmental design, has only relatively recently been acknowledged as a discipline and topic within design research. The last three decades has seen the growth of this discipline, and the terminology relating to environmental design has evolved over this period. This section provides a compact overview of the evolving terminology.

2.1.1 Definitions of common terms

First a selection of quotations was put together to get an overview of the most commonly used terms and their meaning. The selection highlighted the overlap and slight differences in understanding between authors and can be viewed in appendix 2.

The terms Design for Environment (DfE), Environmentally Conscious Design (ECD), Ecodesign, Life-cycle Design (LCD) and Green Design are often used interchangeably. Their common aim is to *reduce* the direct and indirect impacts on the environment from the products and processes. The implementation of these approaches *may* contribute to more sustainable products and processes.

The following terms describe slightly more radical and pro-active approaches. Eco-innovation *aims* to promote step-change environmental improvement and takes environmental improvement as the starting point or stimulus for a project. Sustainable Design *aims* to promote more holistically sustainable outcomes from design by including concerns for other issues such as social and ethical issues. The terms Sustainable Development and Industrial Ecology place the role of environmental design in a bigger, global economic context.

There are other, less common, terms used to describe environmental design approaches such as: Environmentally Sensitive Design (Billett, 1998), Ecological Design (Van Der Ryn & Cowan, 1995) and Biothinking (Datschefski, 2002).

2.1.2 Models that correlate the terms

Various authors have attempted to improve the understanding of the evolving terminology used by identifying relationships between the terms. They have constructed various models that relate the terms. Three such models are discussed here.

ECO2-IRN model

Both Goggin (1996) and McAloone (2000), use the outcomes from the Eco-2 network workshop on 'defining eco-design' as the basis for their models that relate the terms. Figure 2.1 shows the model that resulted from the Eco-2 network workshop as reported in ECO2-IRN (1995).

McAloone's model used the four main concentric circles to explain the terms and the relationships between: Green Design; Eco-design; Sustainable design; and Sustainability. In general, the model presented the practice-based approaches at the centre and the more philosophical approaches towards the outside.

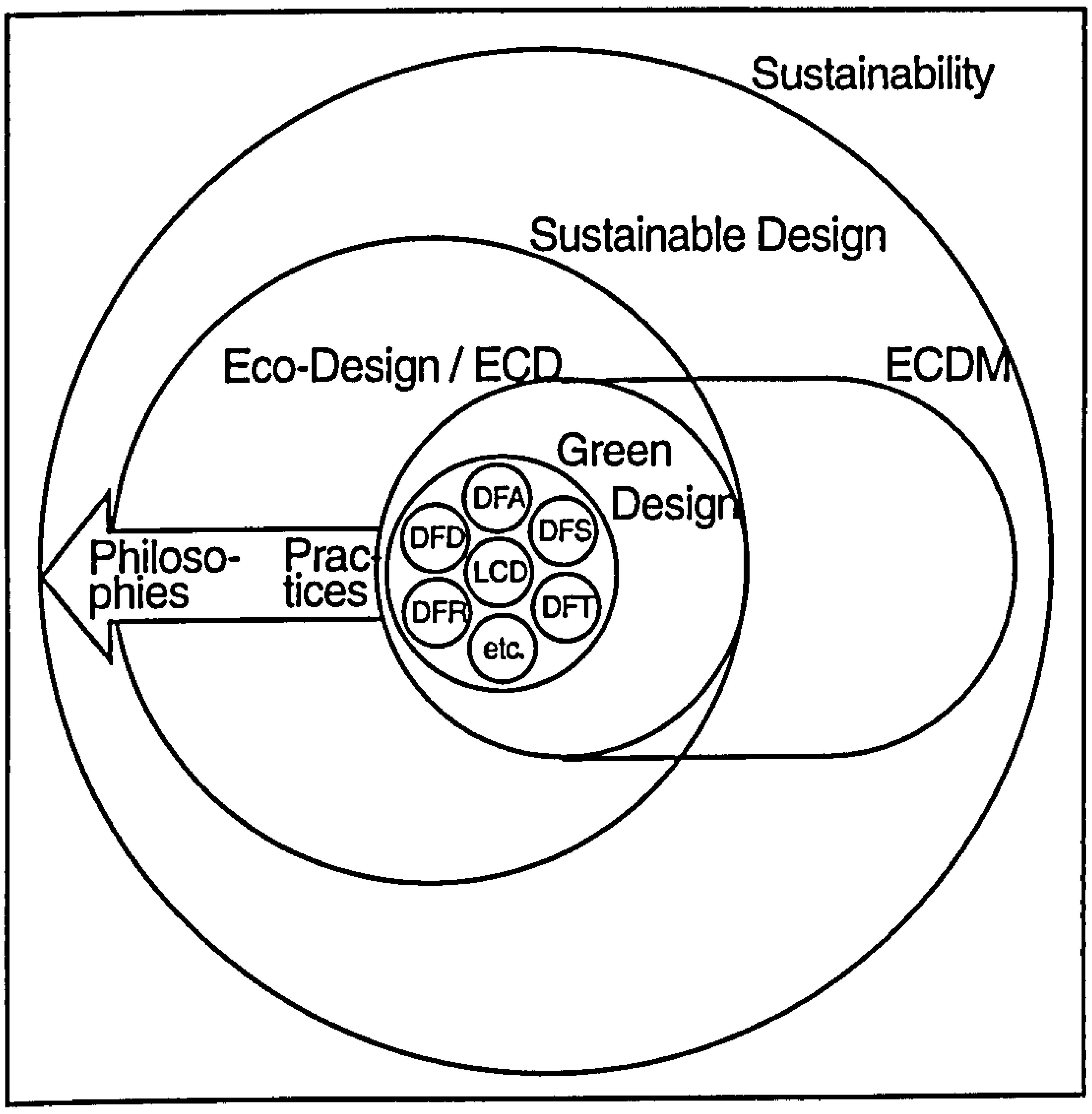


Figure 2.1: ECO2-IRN model (1995) upon which McAloone's descriptions were based.

Although Goggin's model is based on the same Eco-2 network workshop he draws different circles to represent the inter-relationships between the key ideas and definitions. His model is shown in figure 2.2.

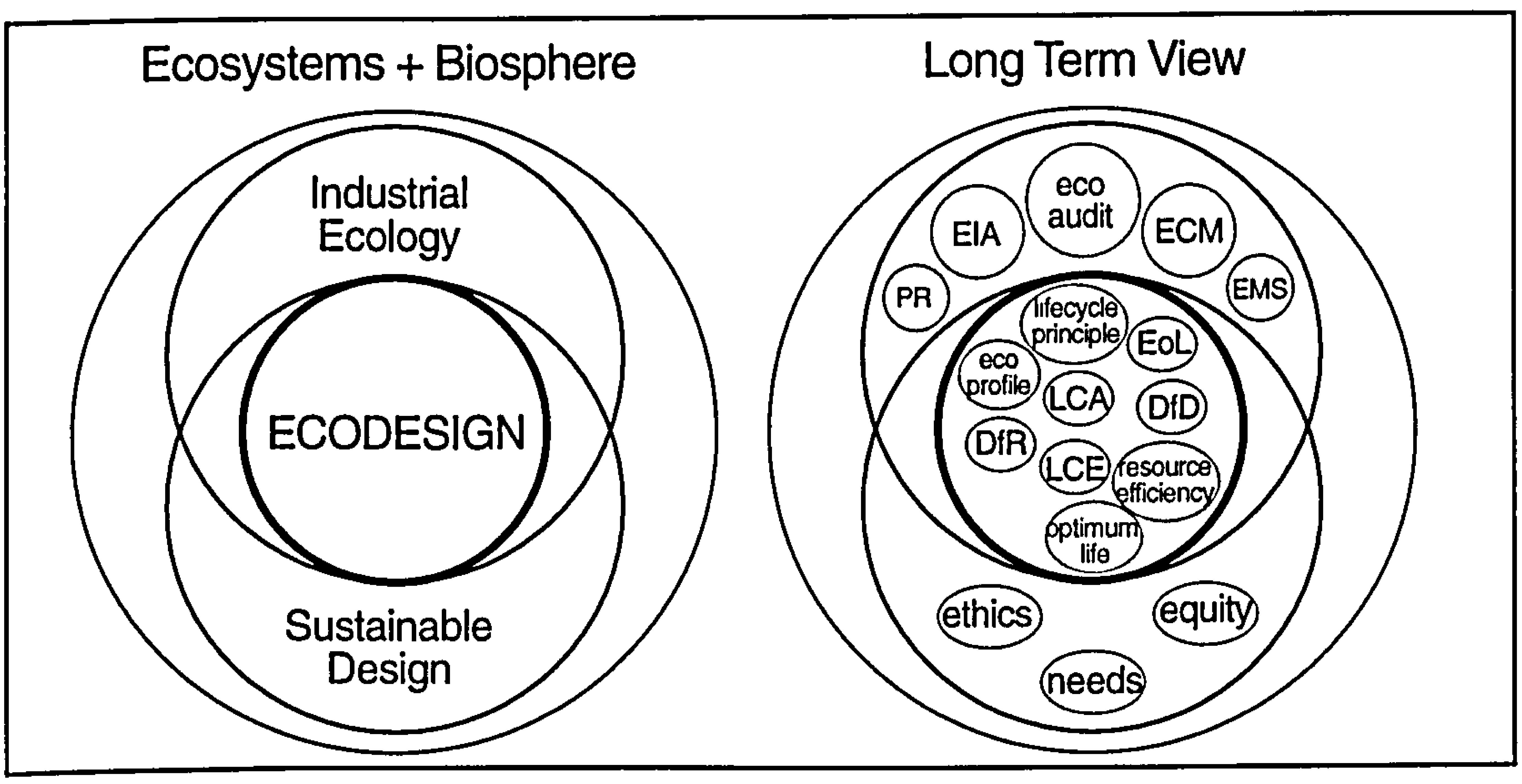


Figure 2.2: Goggin's model based on Eco-2 network workshop (after Goggin, 1996)

These two models are interesting because they show how definitions were evolving at that time. For example, the term 'green design' was used more in the early days of environmental design and may therefore have been associated with the limited approach described by McAloone (2000): practising one or more specific environmental design techniques, such as: Design for Disassembly or Design for Recycling. Goggin (1996) does not draw an explicit boundary for green design in his model.

Tischner's model

Tischner and Charter (2001) present a simple model to clarify the current terms. Their model, shown in figure 2.3, consists of four concentric circles representing the relationship between product design, eco-design, sustainable design and sustainable Development.

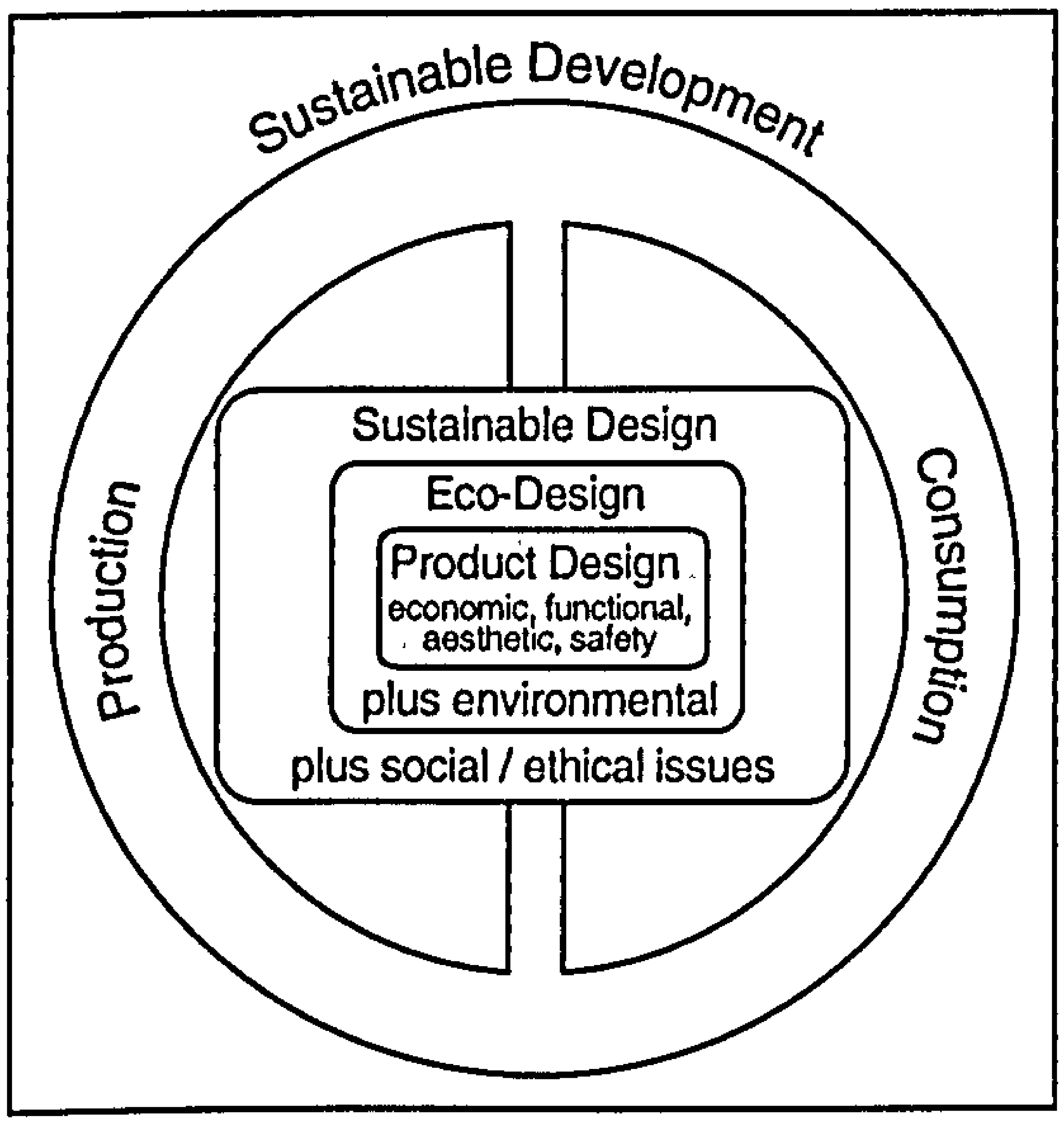


Figure 2.3: Tischner's model (after Tischner and Charter, 2001)

Product design is taken as an important starting point and they describe how product design largely determines the environmental and social impact of a product. Eco-design is the integration of environmental considerations and the life-cycle perspective into product design and development. Sustainable design goes one step further and integrates social and ethical aspects of the product's life cycle. These three approaches form the link between production and consumption and therefore have pivotal roles to play. Sustainable development is the outermost ring and is based on the Brundtland (1987) definition of sustainable development.

They recognize that there is currently little information on sustainable design and few real examples of it. Sustainable development is not presented as a mere 'philosophy' but rather the larger context within which design should operate. This model is useful because it shows the evolution of the terminology towards a simpler model. In general there has been more consensus and consistent use of the terminology in recent times than in the earlier models.

None of the three models include the term eco-innovation. Looking at the eco2-irn model eco-innovation would have to be included near the centre of the diagram because it is a practice-based approach. In Goggin's model eco-innovation would move into the sustainable design circle because it has been defined as a needs –or function – oriented design approach. In Tischner's model eco-design is defined as product design plus environmental issues. By adapting her model it is possible to include eco-innovation. The starting point for eco-innovation must be an innovative approach: product innovation. Figure 2.4 shows how eco-innovation can be defined as product innovation plus environmental issues. The altered version of Tischner's model shows the two approaches – eco-design and eco-innovation – alongside each other both contributing to economic and environmental aspects of sustainable development.

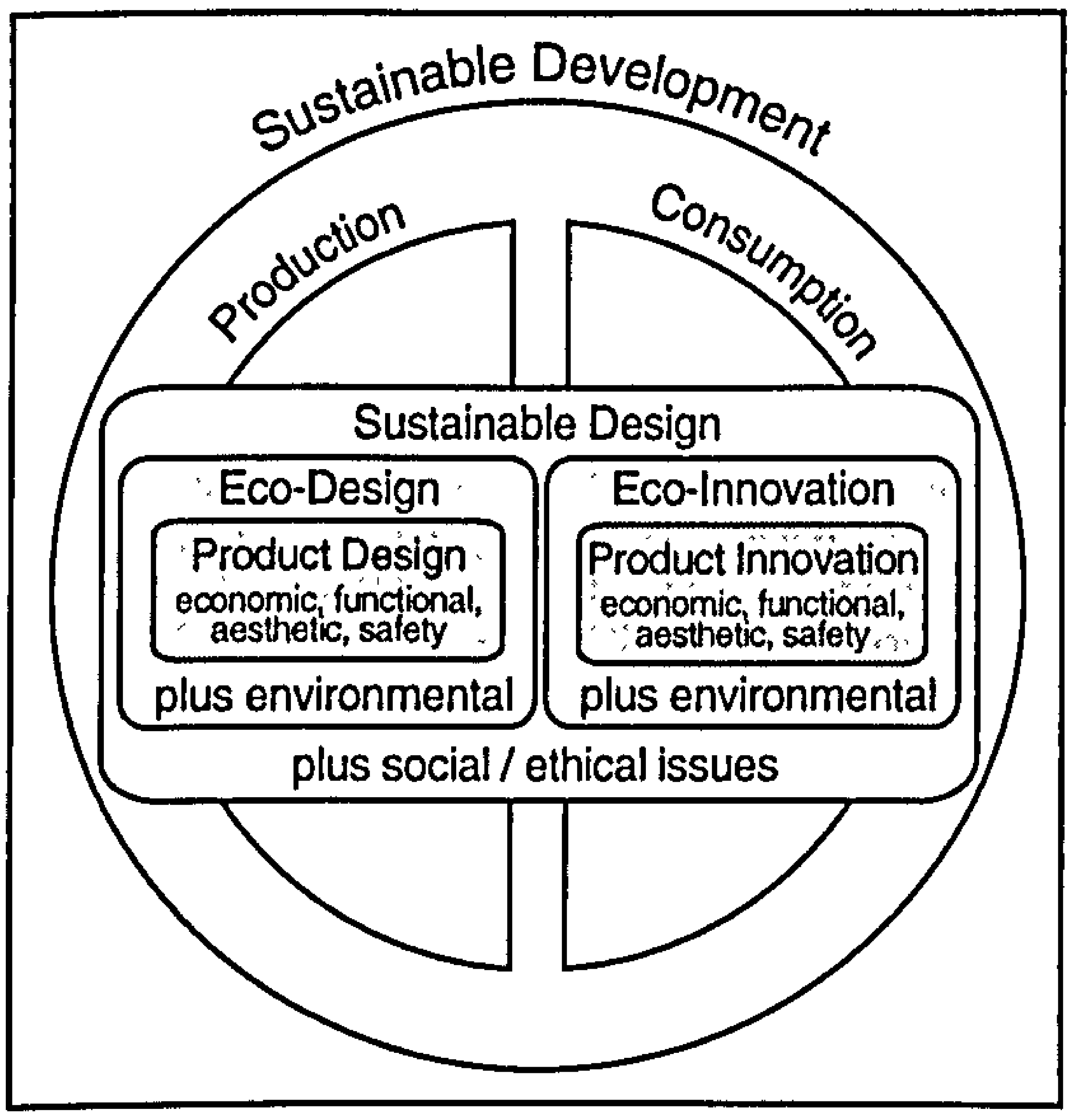


Figure 2.4: Adapted version of Tischner's model to include eco-innovation.

2.2 Drivers and Obstacles in Environmental Design

This section reviews the literature on drivers for and obstacles to environmental design research, to provide a general industrial and academic context for this research contribution.

2.2.1 The Special Role of Designers

Papanek (1972) was the first author to emphasise the responsibility of designers in the shaping of the artificial world. These views are still echoed today (Billett, Goggin & Walker, 1996). Designers' work makes the contributions to society which award status to specific kinds of products and life-styles; designers therefore do have some responsibility for their creations. Designers have the power to create beneficial *or* harmful cultural shifts.

Papanek's later work (Papanek, 1995) focused on inspiring designers to drive environmental design into practice. Authors continue to emphasize the role of designers as they can shape ideas and concepts into practical, and potentially sustainable, products (Dewberry & Goggin, 1996; Mackenzie, 1997; Lewis & Gertsakis, 2001). Some authors suggest that designers are particularly suited to improve the environmental impact of products because they are already trained to deal with the many conflicting aspects of design, and resolve them in products (Billett, Goggin & Walker, 1996).

As the use of LCA tools increased, researchers often discovered that the largest environmental impact of consumer products was in the use-phase of the product's lifecycle. These discoveries have led designers to look more closely at the user-interface of the products they are designing. This interface often prescribes the way a consumer operates their product. The designers' role is critical because they determine the interface between the consumer and the technology underlying the 'shell' of a manufactured product. Lofthouse and Bhamra (2000) state that designers can influence the environmental impact of consumer products by carefully considering this pivotal link between the consumer and the product.

2.2.2 Drivers for Environmental Design

Table 2.1 summarises the literature on drivers for environmental design adoption. Constructing this table made it obvious that the different drivers are intrinsically linked. For example, 'green consumers' can be seen as a societal group exerting pressure for ethical reasons, whilst the demand for 'green goods' can be viewed by business as a commercial incentive to engage. The second example concerns incentives and subsidies, these can be viewed by business as commercial drivers but they are also closely linked to the government's policy decisions and legislation.

Commercial Drivers	Policies and Standards	Societal Pressure (ethical)
Roy et al. (1996) drivers of company responses to environmental problems:		
Green consumers wanting 'environmentally-friendly' products. Cost savings from more energy-efficient, less wasteful manufacturing processes. Commercial advantages of exploiting pollution prevention technologies ahead of competitors.	Environmental regulation (from 1970's onwards)	Corporate social responsibility- pressure from employees, investors and shareholders
Brezet and Van Hemel, (1997) summarise the following internal / external drivers and influences:		
The need for increased product quality The need to reduce costs: energy costs, waste charges The need for innovative power Market demand, public opinion, and environmental requirements in consumer tests Competitors, environmental competition Cooperation with trade organizations and suppliers: increasing supply chain pressure. Ecolabelling schemes	Government Subsidies Take-back obligation The obligation to provide information Norms and standards Environmental requirements for design awards	Managers' sense of responsibility The need to increase employee motivation, social environment The need to improve the image of the product and the company
Tischner and Charter (2001) list factors driving the eco-design as a discipline:		
	Policies (IPP, legislation, eco-taxes, eco-labelling, etc) Standards (ISO14001, EMAS)	
Lewis and Gertsakis (2001) discuss a number of influences or drivers:		
Consumer demand for 'greener' goods The 'environment' as a source of innovation to boost competitiveness.	Governments creating a careful mix of incentives, rewards and demonstration programmes that support business	Non-conforming designer-based groups such as O2 Pioneering universities and research institutes
Tischner (2001) lists the following reasons for practising environmental design:		
Costs are reduced Improved company image leading to better sales Improves innovation capabilities and long-term	Proactively anticipating regulations improves legal compliance and reduces the need for regulation.	

Table 2.1: summary of drivers for environmental design adoption

Commercial Drivers

From table 2.1 it is possible to observe that a strong case is being made for environmental design as a win-win strategy; with commercial success alongside environmental improvements. Van Den Hoed (1997) says there are a growing number of examples of successful environmental design that were driven by opportunities to improve efficiency, which simultaneously led to cost reductions.

Industrial case studies highlight the commercial aspects of business that have been enhanced. For example, Matzke, Corky Chew and Wu (1998) from Apple Computers say that their environmental work has: reduced cost or risk, eco-features valued by customers and enhanced their brand. O'Connor, Blythe and McEnvoy (1998) conducted an industrial case study, and they also stress the potential commercial benefits of environmental improvements: proactive market leadership; enhanced corporate image; greater customer satisfaction; augmented profitability through innovations in materials management and manufacturing; and cost savings through product re-use.

Policies and Standards

The role of government regulation in promoting the adoption of environmental design should be included when drivers are under discussion. Only recently have the policies significantly changed from legislating against 'environmental crimes' towards introducing incentives, subsidies and voluntary standards. Other new phenomena are the new policies that aim to promote more sustainable consumption modes by offering tax reductions for less harmful products and higher taxes for the worst products and activities.

As more environmental regulation comes into place, businesses question how it will affect them. Legislation often describes *what* needs to be done, but not *how* it is to be implemented (Stevels, 2000). Other questions regarding the role of legislation are: can the general principles and recommendations be interpreted differently and how will compliance be enforced anyway?

An optimistic view of legislation as driver is given by Beard and Hartmann (1999) who say that legislation can be transformed from a threat to a driver for business if environmental design constraints are used to overcome innovation lethargy. It is clear that the role of government regulation in promoting the adoption of environmental design is currently a much-discussed topic. In February 2002 a lively email debate took place on the Eco2-network, on the role of legislation as a driver; international examples, opinions, and research were exchanged.

Societal Pressure

Relatively little has been said about the role of *society* in promoting the adoption of environmental design in general. Recent observations do indicate that the anti-globalisation movement, ethical - or green - consumer organisations and positive action campaigns from environmental organisations are contributing drivers.

More comments have been made on the role of various *individual* stakeholders as drivers. Lewis and Gertsakis (2001) highlight the important role that individuals play in driving sustainable and commercially successful design. They list different types of people such as: 'smart thinkers, enthusiastic individuals, committed teams and/or progressive executives'. Beard and Hartmann (1999) also focus on the role of people or 'eco-innovators' to drive environmental design. They stress the importance of a critical mass of such people and the involvement of a greater diversity of disciplines.

Tischner and Charter (2001), Lewis and Gertsakis (2001) all acknowledge that academic environmental design research is one factor amongst many driving the adoption of environmental design as a discipline in industry. In fact, within academic research there are many examples of collaborative projects which improve the links and collaboration between the drivers and different stakeholders described in this section.

2.2.3 Obstacles to Environmental Design

As an evolving research field, the obstacles to adoption of environmental design are little discussed. This may be due to the need for optimism to allow the discipline to grow. As environmental design becomes more established, more critical views are expressed. This section discusses a few of the emerging issues.

Sustainable consumption

One fundamental obstacle is the contradiction inherent in the ultimate goal of 'sustainable consumption' summed up in the UN Agenda 21 report (UNEP, 1992): consumption drives the creation of income, so global consumption must be increased to improve overall 'quality of life'. This contradicts the calls for reduction in overall consumption, but does make it clear that there must be a change in the *type* of consumption growth. Tischner and Charter (2001) say that tackling 'sustainability' is not easy for business and will involve changes or shifts in consumption and production *patterns*.

Industrial climate

Sceptics of environmental design say that the current industrial climate may, to some extent, be prohibitive. Businesses today already have to overcome the following challenges: time-to-market and cost pressures; competing interests and difficult trade-offs; and fast-changing corporate cultures and direction. Environmental design has an extensive reach, from suppliers to customers and everything in between, and is therefore difficult to advocate, support or manage.

Some of the factors given as drivers (section 2.2.2) are sometimes equally referred to as obstacles. For instance, Matzke, Corky Chew and Wu (1998) give the following examples of factors limiting the take-up of environmental design at Apple Computers:

- few legal mandates;
- unclear competitive advantage;
- no commonly accepted standard or measure of environmental impact that has meaning for markets;
- wide range of products or diverse markets;
- financial constraints or cost pressures.

Adopting complex tools

Authors have warned against complex tools and methodologies in general as they may 'blur and burden' environmental design (Lewis & Gertsakis, 2001). However, the most talked about obstacle to the adoption of environmental design within the research community is associated with the reputation of LCA tools. Common environmental design practice includes some analysis of the status quo, which has normally been done with LCA tools. LCA can determine the life-cycle stages at which the greatest environmental impacts occur in order to inform the design strategy to reduce them (Roy et al., 1996). LCA can also ensure that beneficial changes in one part of the life cycle are not detrimental at another stage in the life cycle.

Some of the well-documented limitations of LCA tools are that: they are expensive and time-consuming to employ; the results are not always accepted as scientific due to their heavy dependence on assumptions; and that they may interfere or slow down the design process (Fiksel, 1995; Hook, 1996, Billet, 1996). Holloway (1997) says a balance must be struck between the practicality and accuracy of the analysis.

Several authors warn that adopting analysis tools may limit innovative approaches. Beard and Hartmann (1999) state that adopting tools that focus on impact reduction and efficiency may limit the level of eco-innovation. Sherwin (2000) concludes from his research that successful results can be achieved in projects that do *not* start with an 'analysis of the status quo' and perhaps the use of analysis tools tends to lead to incremental product improvements.

2.3 Review of the tools for Environmental Design

Having taken heed of the warnings concerning the adoption of complex tools, this research went on to look more closely at alternatives such as streamlined tools and strategic environmental design tools. Streamlined tools often compare the environmental merits of new design options against the original design. These tools are still analysis tools, although some have been used as starting points for creative workshops. Strategic environmental design tools are intended to support strategic product planning processes at higher levels of management. The investigation carried out on one of those tools is reported in chapter 3.

Several authors have brought together and categorised tools for environmental design more comprehensively. This section reviews these contributions and makes statements about the tools and methods to be developed in this research.

2.3.1 Analysis tools and improvement tools

Sweatman and Simon (1996a) review a range of tools using two classes of environmental design tools; analysis and improvement tools. The analysis tools show which issues and priorities need to be addressed. The improvement tools facilitate and assist the improvement of the product. Under analysis tools they initially review LCA tools and abridged LCA tools. In a later paper they provide a more detailed breakdown of the different types of analysis tools available (Sweatman & Simon, 1996b). Under the improvement tools they include: workshops, checklists, handbooks, software and pilot projects. Both types of tools have important roles to play in the integration of environmental issues throughout the design process. They stress the need for new tools which will encourage more innovative approaches.
McAloone (2000) used the same categories to review tools and methods. He conducted an extensive survey of 24 industrial practitioners of environmental design and concluded that improvement tools are more favoured by designers and environmental champions. Analysis tools were generally found to be too cumbersome for successful integration into design processes. The improvement tools used most in industry tend to tackle small specific issues or tend to be 'in-house' company specific tools.

From both reviews it is clear that there were relatively few generic improvement tools developed. Workshops, pilot projects and concept demonstrator projects were being conducted at that time and the experiences gained from those should have led to the development of more improvement tools. This research journey started with the analysis of two such concept demonstrator projects and their relation to the design process (one of them is described in chapter 3).

2.3.2 Environmental design manuals

Two important reference manuals (Gertsakis, Lewis & Ryan, 1997; Brezet & Van Hemel, 1997) brought together academic expertise and pilot project experiences from industry. Both of these manuals provide an environmental design process based on integrating environmental issues into conventional, established design processes. Both suggest the use of a number of analysis and improvement tools and design workshops. The improvement tools are extensive design checklists and descriptions of potential environmental business strategies that could be followed. The environmental design workshops suggested the use of techniques similar to those from conventional product development practice. However, in environmental design workshops, the objectives and the key starting points for the sessions focus on improvement of the product's environmental performance.

Relatively little research has been done on the idea generation process within environmental design. This research focuses specifically on this workshop-style activity within the environmental design process. The aim is to increase the effectiveness of eco-innovation workshops by developing specialised tools and methods.

2.3.3 Tools Decision Support

From 1995-1998 a large group of researchers were funded to develop an environmental design decision support model which would be of practical benefit to the electronics and electrical industry (McAloone, 2000). The project was called Design for Environment Decision Support (DEEDS). The project's aims were to: build decision-making models, test methods and tools and evaluate their use in industry.

The final outcome from the project was the Ecodesign Navigator (Simon et al., 1998) a resource book which reviews 54 environmental design tools and methods, explains how environmental design can be integrated into a product development process and provides a framework for selecting the tools and methods. Based on their extensive research of industrial practitioners they developed the Analyse- Report- Prioritise- Improve (ARPI) framework. Those ARPI activities define both actions and strategies that successful environmental design entails. Their review of tools and methods is organised on a map (shown in figure 2.5), where one axis represents the ARPI- activities and the other axis represents the 'design level' at which the activity is taking place. The design level ranges from 'general' or systems design to 'specific' or component design.

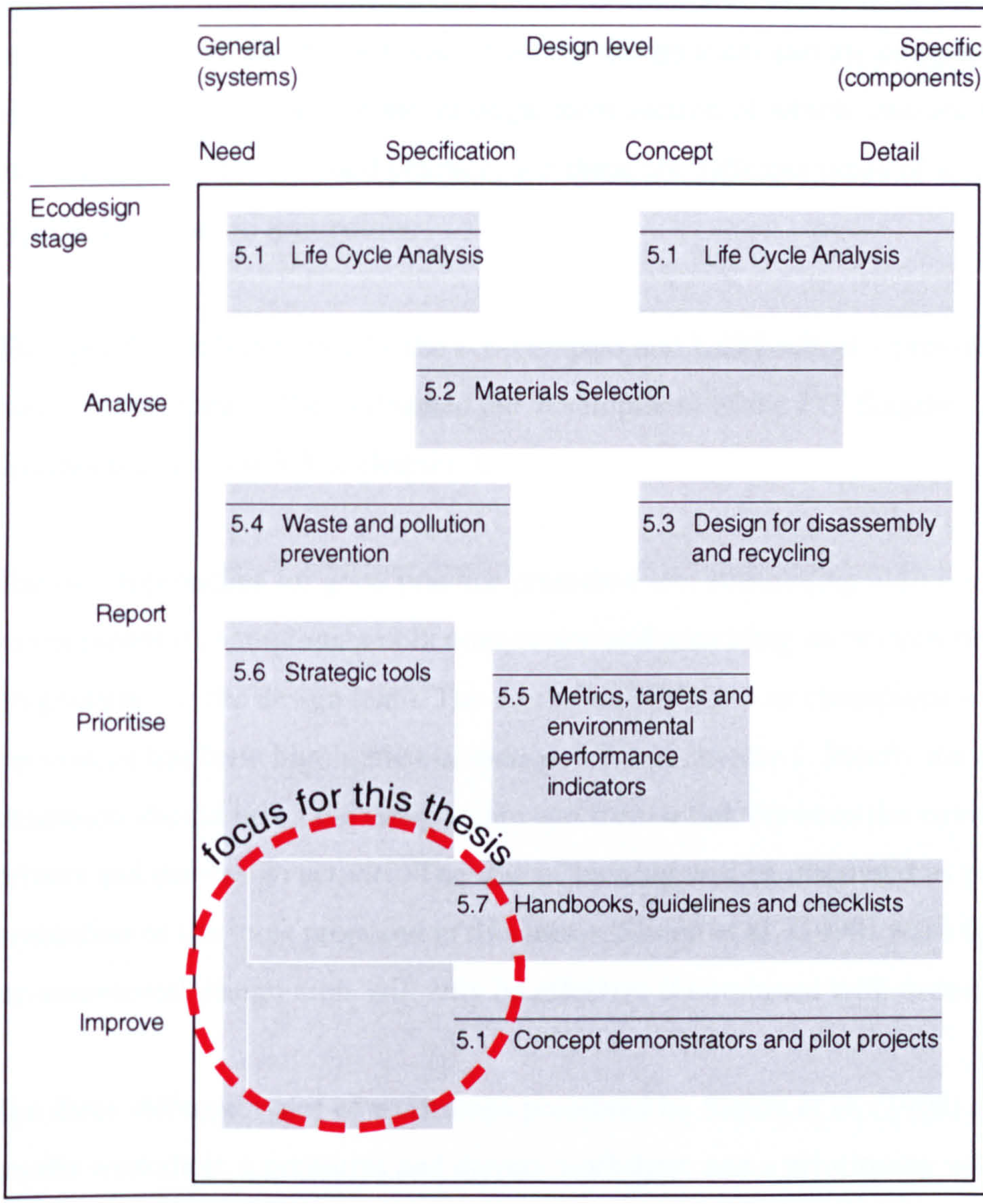


Figure 2.5: ARPI tools map after Simon et al. (1998)

This thesis contributes tools to the Improve part of the (ARPI) framework and aims to encourage design at higher levels of the system hierarchy. Within that quadrant of the tools map we find three categories of tools:

- handbooks, guidelines and checklists;
- concept demonstrators and pilot projects;
- and strategic tools.

The handbooks and demonstrator projects do sometimes include descriptions of workshop-style activities, but there are no specific tools presented to facilitate those activities. The strategic tools presented in the resource book are most relevant to this thesis. These are the methods that should be used at the beginning of a project. They are intended improve the interactions within the design team and the company as a whole. Seven tools are presented in the strategic tools section of which: two are specific tools; two are approaches for good practice; and three are different types of workshops. Each type is discussed in turn below.

The specific tools presented – the eco-compass and LiDS-wheel – provided a starting point for this thesis. They informed the development of the PIT diagram and are discussed in section 3.3 of chapter 3.

The two approaches for good practice presented are: stimulating individuals to act as environmental champions within companies; and providing an environmental training programme for the design team. The role of individuals - or champions – in eco-innovation has been highlighted in section 1.2.1 of chapter 1. Ideally the environmental champion should be on the design team and form a link between the environmental drivers and the design activity. The role of training will be discussed as part of the evaluation of the tools proposed in this thesis. Simon et al. (1998) warn that many environmental design tools will only be effective if combined with training.

The three different types of workshops presented by Simon et al. (1998) are: an LCA-results workshop; a pressures and drivers workshop; and a prioritising workshop. The LCA-results workshop is intended to translate the quantitative results from an LCA study into issues and comparisons that can inform a product redesign. The pressures and drivers workshop is a very general awareness-raising workshop for teams new to environmental design. The prioritising workshop brings the participants together to establish the priorities for the project and the measures to gauge the product's improvements. All three of these workshops are based on existing environmental design practice and support the established incremental approach. The workshops proposed in this thesis are intended to generate more radical concepts for environmental impact reduction. This thesis contributes specific tools to support those eco-innovation workshops. The tools proposed fit within the highlighted quadrant of the tools map shown in figure 2.5.

2.3.4 Tools for sustainable design in practice

Tischner (2001) has more recently created an overview of tools used in environmental design. She lists 27 tools for sustainable design used in current literature, practice and her own consultancy. Figure 2.6 shows how she organises them in a map according to their purposes in the design process and their complexity.

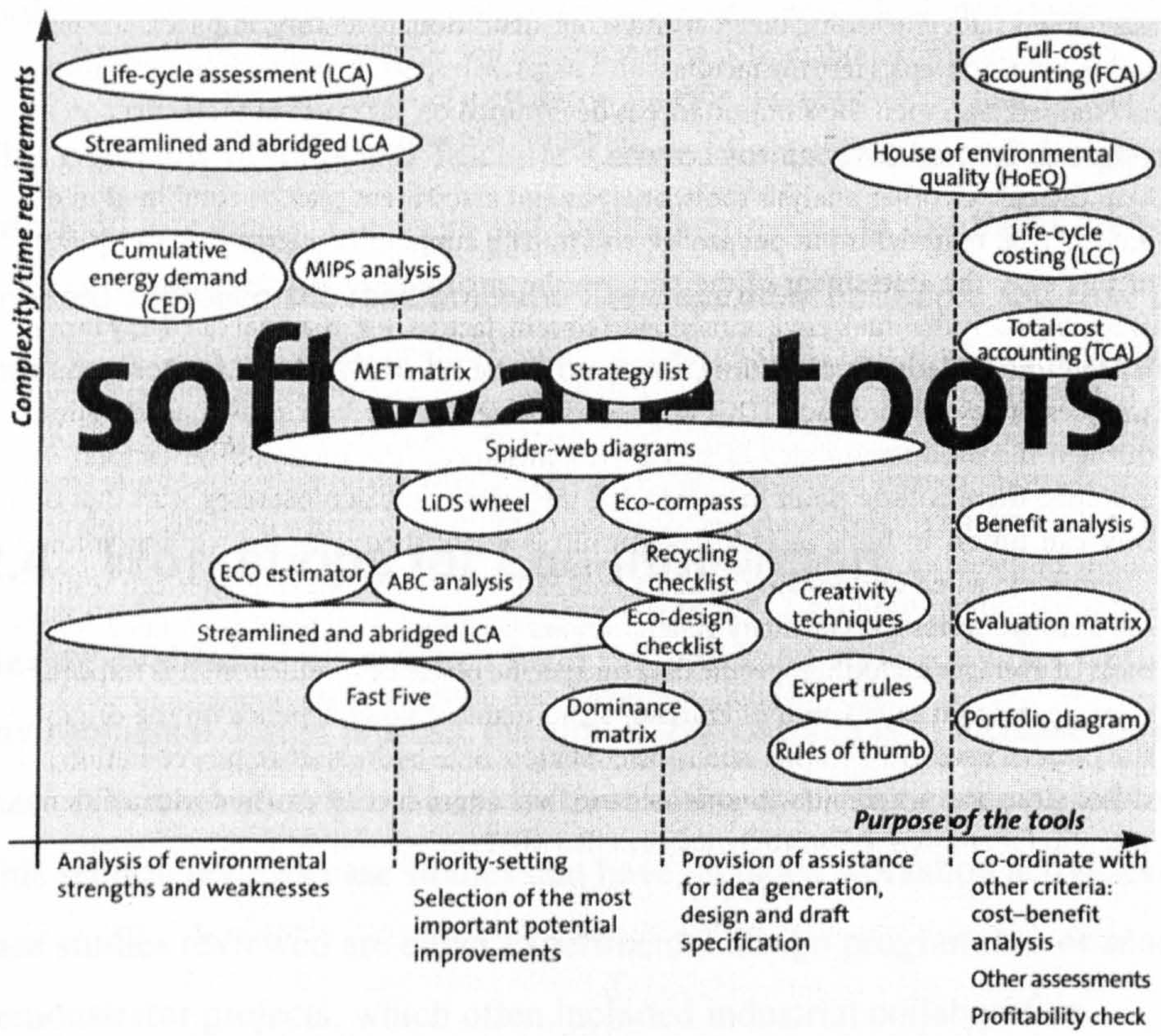


Figure 2.6: Classification of tools useful for environmental design after Tischner (2001)

The four purposes of the tools she lists are: analysis, priority setting, implementation and co-ordination with other criteria. She advocates an action-oriented approach, focusing on the implementation tools. She says that the application of simple environmental design tools enable stakeholders to absorb quickly the important aspects of environmental design through practice. Examples of tools used in pilot projects are: spider diagrams, rules of thumb, creativity techniques and eco-design checklists. These implementation tools offer simple environmental design criteria in a situation specific manner, without a lot of time-consuming analysis. Where development schedules, finances and the availability of personnel are tight, action-oriented approaches enable appropriate environmental design focus at early stages in the development process.

She concludes that approaches for environmental design should be diverse and include: top-down management action as well as bottom-up action from project personnel; and short-term 'quick wins' as well as long-term strategies. Her consultancy experience has shown that small and medium-sized companies particularly express interest in simple tools.

This overview of tools and Tischner's advice for environmental design practice have informed this thesis. The tools and methods proposed in this thesis are part of the action-oriented approach she recommends. The tools must be simple and easy to introduce and must be flexible enough to be used by participants from different company levels.

2.4 Workshops for Eco-innovation

Having established the research focus on workshop-style activities within the environmental design process, the aim of this research is to increase the effectiveness of these eco-innovation workshops by developing and testing specialised tools or methods. This section reviews case studies that have included workshop activities. Most of the case studies reviewed are either experimental design programmes or academic demonstrator projects, which often included industrial collaboration.

Authors have highlighted theoretical benefits of workshops for step-change environmental design. Quist and Vergragt (2000), for example, say that to achieve really new solutions, ideas and directions, creativity needs to be enhanced in workshops and the design process in general. Mainstream Creative Problem Solving (CPS) theory offers existing tools and methods which could be applied more. They warn that workshops are only part of a complete design process. Street (1997) highlights the benefit of workshops to bring together different stakeholders and involve them in environmental decision-making processes. She investigated the use of 'scenario workshops' from the Technology Assessment methodology. In general, she concluded that workshops are a good way to generate a large number of ideas, but that tools for group sessions could be improved.

The review of the projects and case studies below focuses on the descriptions of the workshop sessions and methods used to facilitate those sessions. For each project brief summaries of the background to the project, the workshop session and the outcomes are given. Chapter 3 looks at one of these case studies in more detail and looks at the actual output from the workshop in relation to the design process.

2.4.1 Review of cases with workshop sessions

'Vacuum cleaner workshop' (Sweatman, 1997)

Background: This project was conducted as part of the DEEDS project reviewed in section 2.3.3. One of the project's objectives was to investigate environmental considerations at the beginning of the design process. A more specific objective was to work with a multi-disciplinary design team, to generate concepts prior to the product specification stage. The product chosen for the case study was a vacuum cleaner.

Workshops: The workshop programme was based on the best available literature on environmental design workshops at the time (Fussler & James, 1996; Brezet & Van Hemel, 1997). First, the team was introduced to the environmental impacts of an existing vacuum cleaner. Subsequently, they went through several stages of generating, filtering and prioritising ideas, based on four different 'starting points' for environmental design. The final stage of the workshop was to link these ideas and to embody them in a new vacuum cleaner.

Outcomes: This workshop resulted in a range of commercially promising ideas for the vacuum cleaner, as well as findings on the workshop process itself. The strengths and weaknesses of the process were distilled from a brief feedback session at the end of the workshop. The most interesting of these findings were that:

- the 'Post-it note' brainstorming method was useful;
- more creative methods could have been used;
- focusing on a smaller number of environmental issues would have been better;
- the participants would prefer to spend less time filtering the ideas generated.

Philips Eco-design programme

Background: Philips Sound and Vision have a history in incremental environmental design and use a range of tools. In the 90's environmental design became more product-focused and the next stage for Philips Sound and Vision was to aim for step-change improvements in their products. A 'green TV' demonstrator project was run, which aimed to incorporate all their environmental knowledge at that time. The 'green TV' never went into production but was used as an internal benchmark for future generations of that product. They went on to develop 'advanced concepts' for other products including telephones, faxes and audio products (Stevels, 1998) some of which were taken through to production.

Workshops: Their guidelines mainly describe the managerial aspects of environmental design, but include a step-by-step description of the recommended process for pilot projects. This process includes various analysis and prioritising activities, including conducting a 'brainstorming session' and evaluating the outcomes.

Outcomes: In May 1998 Philips launched a green product range presented in the catalogue 'From Green to Gold' (Philips Electronics, 1998) and later published their ecodesign guidelines (Meinders, 1999) which summarize the lessons learnt from their environmental design pilot projects.

Electrolux project 'Ecodesign kitchen of the future' (Sherwin, Bhamra, & Evans, 1998; Thompson & Sherwin, 2001; Sherwin, 2000)

Background: Previously, environmental design at Electrolux had been mainly analysis- and technology-led; this project investigated the potential of a design-led environmental approach. The project was a collaboration between a concept design team at Electrolux and environmental design experts from Cranfield University. The project goal was to provide a suitable entry for an international design competition. One of the aims for Electrolux was to develop relevant environmental design methods and practice. The aim for Cranfield University was to stretch the boundaries of current environmental design practice.

Workshops: The project ran over several months but the main two-day workshop was held at the beginning of the project. In this structured workshop the participants came together to establish a working relationship and focus the aims, project brief and project agenda. Several information-sharing activities were held and one idea-generation session was held, using the conventional 'Post-it note' brainstorming method. At a later stage, the workshop outcomes were developed into product ideas and new concepts for the competition entry.

Outcomes: After the workshop the outcomes were presented as summaries under the following headings: the design brief, kitchen and project boundaries, kitchen processes, target audience and corporate values. The outcomes from the brainstorming sessions were summarised as Eco-Ideas maps to assist the designers in the further development of the project. These Eco-Ideas maps did not use a particular structure to organise the outcomes. The final outcomes were seven new product concepts, several of which represented new types of products – or step-change concepts. These concepts may not feed directly into product development at Electrolux, but do present possible new business opportunities and raise awareness of step-change environmental design.

'The Future of Clean Textiles' project

Background: This project was initiated by a Dutch governmental programme (DTO) to develop methods for sustainable, technological innovation. The subject area chosen was 'The Future of Clean Textiles'. The aims were to test methods for working with multi-disciplinary groups in workshops and to obtain useful ideas for the future of clean textiles.

Workshops: At least two different workshops were held to develop new approaches to clean textiles: 'Sustainable washing services' (Vergragt et al., 1995) and 'Toward sustainable clothes washing: technology, services and cultures in the future' (Van Den Hoed & Vergragt, 1996). The first workshop is most interesting from a methodological point of view. A personality test was used to help select the workshop teams and an experienced creativity facilitator was involved in the running the workshop. Less well-known creativity techniques were used to generate ideas for product-, process- and culturally-oriented innovations. The techniques used - the Future Perfect process and the 'Force-Fit' method from Synectics - were described and reported by Tassoul (1998).

Outcomes: The participants gave feedback on their experience and were positive about the collaborative opportunity, techniques used and outcomes achieved. Tassoul (1998) gave tips for the running of such workshops and highlighted the difficult stages. The workshop enabled the participants from diverse backgrounds (industry, consumer organisations, universities and applied research institutes) to successfully develop shared visions and a sense of ownership of the radical step-change concepts produced. The first workshop provided a large number of ideas which were difficult to translate into practical projects. The second workshop was therefore conducted to define more detailed, practical project proposals.

The SusHouse project (Quist & Vergragt, 2000; Quist, Vergragt & Young, 1999).
Background: The 'Strategies towards the sustainable household' (SusHouse) project was an EU-funded research project which ran from January 1998 to June 2000 and involved six research groups from five different countries. The focus for the study was on 'households and consumption' and investigated how step-change environmental improvement could be achieved through system-level innovation. One of the main obstacles for such system-level innovations are the complex stakeholder alliances required. The project aimed to provide proposals, policy recommendations, identification of knowledge gaps and new stakeholder alliances. Another important objective was to develop the 'stakeholder workshop methodology' itself and draw conclusions on its limitations.

Workshops: The 'stakeholder workshop methodology' is described as a seven-step process including two workshop sessions. The first 'stakeholder creativity workshop' was professionally facilitated and aimed to create ideas for future scenarios and bring together the different stakeholders. The second 'back-casting workshop' aimed to result in proposals for implementation and stakeholder alliances. The workshop employed established brainstorming methods and the Back-Casting technique.

Outcomes: The research teams later developed the results from the workshops into Design Oriented Scenarios (DOS). These scenarios were assessed for their potential environmental improvements, economic viability and consumer acceptance. The scenarios were widely disseminated and may currently be informing new action and policy agendas. Some observations were made on the workshop organisation and stakeholder management. The workshop methodology was successful in involving stakeholders from a wide range of societal groups.

EcoReDesign™ Programme

Background: This Australian collaborative programme between academia and industry ran for three years from 1993 and was government funded. It aimed to show what environmental design could achieve in terms of commercial success and environmental benefit. The programme demonstrated how environmental issues could be integrated into the design process within a commercial context. The Guide to EcoReDesign™ (Gertsakis, Lewis & Ryan, 1997) describes the proposed design process as a series of steps. It highlights critical phases of the process and the integration of specific design tools. Important parts of the guide are the reports on six successful product case studies.

Workshops: Almost all case studies included an ideas- or evaluation-workshop early in the process. Some of the workshops were more specific and investigative, where others were more conceptual. All workshops helped to forge the relationships between the different stakeholders. The stakeholders included were: diverse personnel from the companies, academic staff from different design disciplines and sometimes external specialists or consultants.

Outcomes: The more conceptual or 'function-oriented' workshops seemed to result in more innovative products. For example: the kettle workshop explored and generated responses to boiling water; the dishwasher workshop explored and generated environmentally oriented responses to dishwashing. The results from both these projects were implemented and resulted in award-winning innovative products. The success of the programme meant that more Australian companies became interested in conducting such projects (Gertsakis, 2001). A two-year programme was set up in 1997 to continue to provide the subsidised assistance for industrial projects. This programme, EcoReDesign™ stage 2, led to 13 more company case studies and more specific literature on implementing environmental design in different industries.

Kathalys Programme (Kathalys, 2002)

Background: The Dutch Kathalys programme is similar to the Australian EcoReDesign programme; it is a government-funded, collaborative programme between academia and industry. The Kathalys programme was established in 1998 and is one of the outcomes from the many years of research in environmental design carried out at the Technical University in Delft. Kathalys employs about twenty staff to work as concept developers, planners and designers on industry projects. Their aim is to pursue and implement innovative, environmentally oriented concepts to create a 'critical mass' of success stories in industry.

Workshops: Their work includes the exploration of technology and opportunities for specific 'sustainable innovations' that could be successfully marketed within a 5-10 year time span. The Kathalys 'target identification' process often includes orienting workshops with specialists from the fields of science, business and government. These workshops, their tools and methods have not been described in detail.

Outcomes: Often, the outcomes from their workshops are the transformation of rough ideas into feasible initiatives. Subsequently, industry partners are identified; they bring their corporate objectives and the market opportunities to the project. The programme's first successful results are currently emerging.

Doors of Perception 3 workshop (Doors of Perception, 1995)

Background: 'Doors of Perception' is an international conference and knowledge network for design focusing on information and communication technologies (ICTs). In 1995 their third event was titled 'info-eco' and investigated the role that information technology could play in developments towards sustainability. The 'info-eco' event consisted of: 'pre-season' workshops, the launch event, and the main workshop session followed by the two-day conference where the results of the workshops were presented to a large audience.

Workshops: The main workshop session took place over three days, on three different topics and involved 180 participants divided into 12 teams. The brief for the workshop was: 'to explore info-eco scenarios, to focus on practical applications and to visualise them.' The three workshop topics were: feedback, caring for matter and communities. No details are given on whether any tools or methods were used in the workshops. The sessions were prompted with a number of open questions.

Outcomes: The results from the workshops were presented at the conference and panel discussions on each of the workshop topics were conducted. Perhaps the lack of structure explains why these workshops lead to more questions being raised than answered. They concluded that the design community taking part in this workshop found it difficult to discuss and 'give form' to the value-related environmental issues. Some of the workshop groups continued to work together after the event. The Netherlands Design Institute went on to create new structures and methods for workshops and used the findings to investigate further the 'action potential' from that info-eco debate.

The Eternally Yours congress

Background: The Eternally Yours foundation was started by one of the workshop groups from the Doors of Perception 3 event in 1995. The aim of the foundation is to gather knowledge and experience about the cultural factors which determine the life span of products, and about possibilities for the elongation of product life times (Eternally Yours, 1998). Throughout 1996 and 1997 expert meetings were held and in April 1997 the Eternally Yours congress was held. The aim of the congress was to deepen insights into extending product longevity and improving product endurance.

Workshops: At the congress 150 people took part in workshop sessions. The congress resulted in the publication of a popular book (Van Hinte, 1997) and further publicity. Subsequently, the foundation has begun to offer their services as consultants and organisers of 'guiding workshops'. They offer internal and external workshops. The internal workshops are intended for companies interested in this subject. Specialists from different disciplines such as: anthropology, economics, communication, design, might be brought in to contribute to the workshop. The external workshops are intended to bring together different companies and institutes to openly exchange knowledge and experience.

Outcomes: The foundation has undoubtedly been successful in raising interest in this particular aspect of environmental design. They have not reported to what extent the workshop sessions have contributed or how many consultancy workshops have been conducted to date. The foundation has collated interesting graduate and post-graduate projects on this topic.

O2 Challenge workshop (O2- network, 1998)
Background: O2 is a global network of environmentally aware designers across 16 countries. The network explores new design possibilities that promote respect for the environment. O2 has been involved in numerous activities including exhibitions, conferences and workshop events. In November 1998 an international design workshop took place in Rotterdam called the O2-Challenge.

Workshops: The workshop event examined how both business and the environment can be sustained in the long run. The aim was to generate ideas for sustainable business ventures. Seven themes were chosen to work on such as: mobility, quality of life, urbanisation, logistics, etc. The 160 participants worked in 15 workshop groups headed by a project leader, with a dedicated observer assigned to each team. After working together for two days the teams had to design an exhibit for their sustainable business concept and act out a commercial. No tools or techniques were introduced in the workshops although each team had access to two professional 'creativity facilitators' who had created a walk-through visual experience to spark new ideas.

Outcomes: The event was certainly considered a great success by the participants. However, it is unclear to what extent the workshop environment, facilitators and walk-through visual experience affected the output. Two of the sustainable business concepts were taken on by volunteer 'venturers' and explored further with help from the Kathalys programme. The outcomes from those follow up projects were presented in 1999.

2.4.2 Workshop review conclusions

Examples of workshops from the following settings were reviewed: designers' networks, collaborative projects, academic research, support institutes and industry practice.

The workshops varied in length from a few hours, to a few days depending on the setting and aims of each project. The aims of the workshops varied from: creating new business opportunities; raising awareness of environmental design; exchange of knowledge and experiences; to the investigation of the workshop methodology itself. The output from the workshops ranged from: product concepts; idea-maps; methodology feedback; new business initiatives; to market launched products. An important observation made was that the more 'function-oriented' workshops seemed to result in more innovative products.

Many have emphasised the role of the workshop in bringing together the diverse stakeholders required for step-change projects where changes have to be made at the 'system-level'. Most authors felt that stakeholder alliances were successfully forged in their workshops.

Tools and methods

Most workshops reviewed were run with little structure, however, some had agendas or programmes of activities. Other workshops employed professional creativity facilitators or used workshop leaders to structure the session.

The classic Post-it note brainstorming technique was the most commonly used method, although a few workshops experimented with more advanced creativity techniques from mainstream practice such as: back-casting, force-fitting, future perfect and using personality tests to compose the workshop teams. None, however, have analysed the effectiveness of those tools.

Some of the authors conducted feedback sessions at the end of their workshops. Aspects participants considered successful were:

- the 'Post-it note' brainstorming method;
- a sense of shared ownership of the ideas;
- the increased awareness of potential for change;
- the improved stakeholder collaboration.

Aspects of workshops that participants thought could be improved were:

- more creative methods could be used;
- focusing on a small number of environmental issues;
- less time conducting analytical activities;
- the translation of ideas into practical projects;
- identifying the action potential from the outputs.

It is difficult to draw firm conclusions about the effect of the different workshop attributes, as there are no examples where a workshop was repeated in different circumstances or conducted in a controlled environment.

2.5 Conclusions

This chapter has provided a brief overview of the terminology, drivers and obstacles of environmental design. A closer look was taken at tools for environmental design and case studies that include early-stage workshops.

A strong case has been made for environmental design as a win-win strategy for business. The exact role of legislation in promoting environmental design has been questioned. Environmental design drivers are intrinsically linked and academic research can help create the links between different drivers of environmental design and the stakeholders involved.

Workshops

Workshops at early stages of the design process offer a promising approach for bringing together the diverse participants required to generate innovative ideas. Workshops have also been used to develop environmental ideas into appropriate solutions that can be taken up in industry.

Relatively little research has been done on the idea generation process within environmental design. When tools or methods have been used, their effectiveness has not been tested or analysed and there are no examples of workshops conducted in a controlled environment. This research focuses specifically on the workshop-style activity within the environmental design process. The aim is to increase the effectiveness of eco-innovation workshops by developing and testing specialised tools and methods.

Tools and methods

Tools and methods for environmental design that are too complex may slow down the design process or even limit the level of innovation. This research contributes simple tools that can be applied in the early stages of the design process and assist different participants. Workshops facilitated by simple tools should enable participants to absorb quickly the important aspects of environmental design through practice. Few simple tools have been developed which can be non-intrusively integrated into existing team design practice. This research develops and tests such tools using knowledge from mainstream design research.

Chapter 3 Development of the PIT diagram

The main aim of this research is to increase the effectiveness of eco-innovation workshops by developing specialised tools and methods. This research makes two major contributions to tools and methods; the first of these is the Product Ideas Tree (PIT) diagram. This chapter describes the development of the PIT diagram, as it occurred.

This chapter starts with a closer look at one of the workshops reviewed in the previous chapter (section 2.4.1); the actual output from the workshop is reviewed in relation to the design process. One methodology for strategic environmental planning from industry is also reviewed.

This chapter tests whether the outcomes from the workshop and the expected outcomes from the methodology did actually address environmental concerns at the early stages of the design process. Two evaluation tools were developed, based on a linear model of the design process, to determine at what stage of the design process the workshop activity was focused. The use of the evaluation tools showed that the ideas and outcomes from the workshop and the methodology were applicable at different stages of the design process.

An opportunity was identified to develop the PIT diagram further as a recording tool, to improve workshop sessions by recording a larger quantity of ideas and identifying the relationships between them, thus enabling the participants in workshops to see their interests and inputs in relation to the 'bigger picture' or system. The linear model of the design process proved to be limiting when the PIT diagram was used as a recording tool.

3.1 Introduction to evaluation tools

Two novel evaluation tools were developed specifically to evaluate the type of ideas generated in the workshops and the intentions of methodologies. The two tools developed were the Standard Design Process Form (SDPF) and the Product Ideas Tree (PIT) diagram. These two tools contribute to the consistency of a review by providing structured documentation of the methodologies and idea output from the workshops. The use of these evaluation tools was not extensive but did provide new insights into aspects of ideas capture and the role of the design process model.

First, the 'Standard Design Process Form' (SDPF) is described, which was developed to understand where existing eco-innovation tools and methodologies fit within a design process. This form is used to describe *where* idea generation is taking place in the design process, and what *type* of design activity is being conducted.

Second, the Product Ideas Tree (PIT) diagram is introduced, which was developed from a need to review the output from workshops in further detail. Tassoul (1998) suggests that it is not easy to summarise the outcomes from creativity workshops. He states the need for frameworks to cluster results from workshops. The PIT diagram is a novel method for clustering ideas and documenting outcomes clearly and is different from any existing idea-recording or 'mapping' technique because the ideas are simultaneously clustered according to eco-innovation strategy 'headings', which are also placed within the applicable stage of the design process.

3.2 Standard Design Process Form (SDPF)

The Standard Design Process Form (SDPF) splits the development of a product down into chronological stages. This enables a more structured and consistent review of workshops or methodologies used. Each stage has a distinct starting point and an expected output type in terms of work. The SDPF is a simple form based on a design process developed by Inns (1994) for product/industrial designers, which in turn is based on a British Standard design process: BS 7000 (BSI, 1989). The SDPF is a version of a design process adapted for eco-innovation processes where the output types defined are those typically expected from environmental design projects; e.g. new *environmental* business strategy, *eco-innovation* project plan, as shown in figure 3.1.

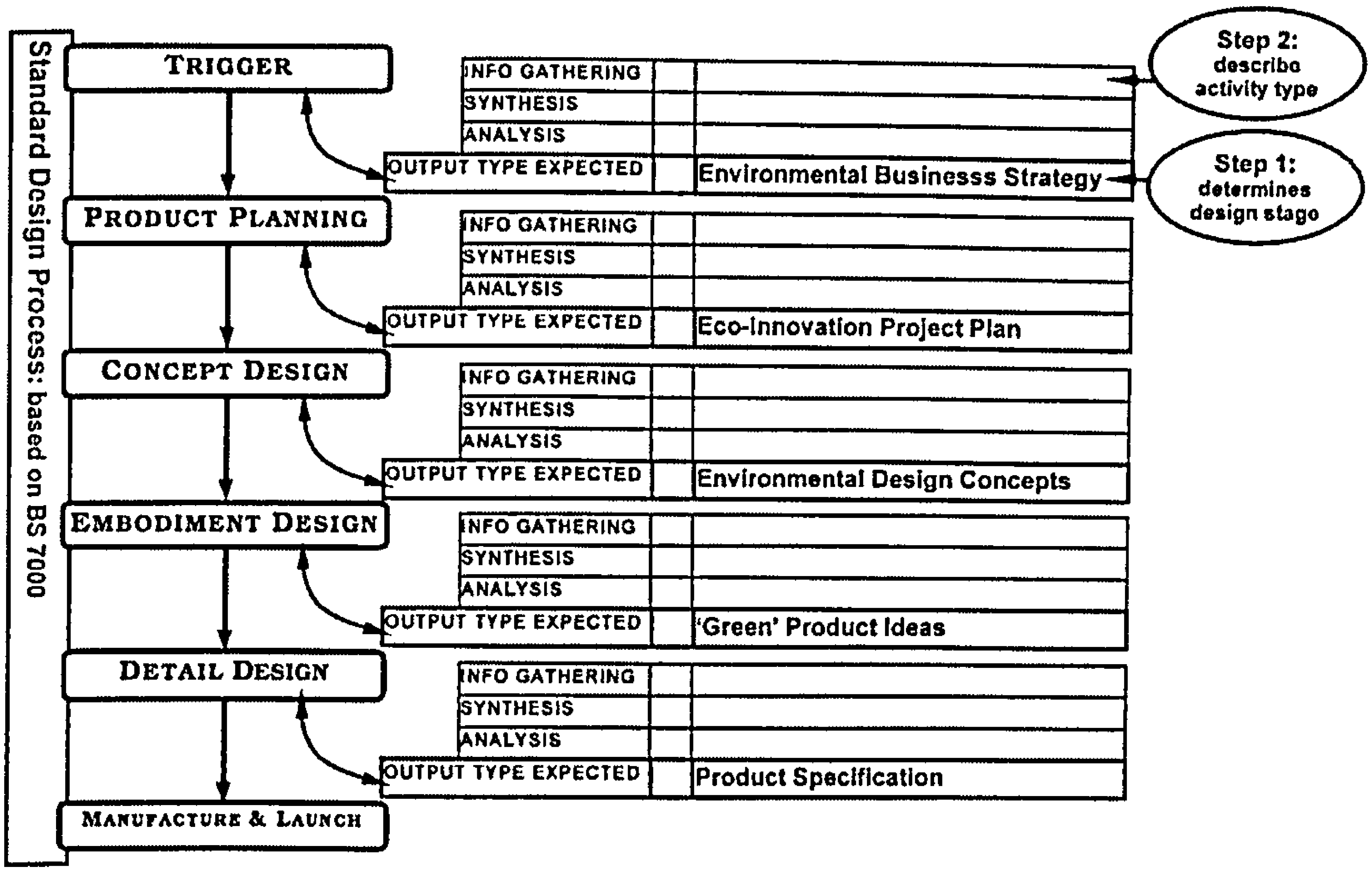


Figure 3.1: The SDPF showing the output types expected at the stages

The SDPF can be used to identify where existing eco-innovation tools and methodologies fit within the product development process. This is done by taking the relationship between the 'design stage' and the 'output type expected' and using it in reverse:

- Idea output observed in the case study identifies the *stage* of the design process at which the activity is taking place. The idea output is entered in the form indicated by Step 1 in figure 3.1.
- Identifying the *type* of activity being conducted at that stage of the design process. Design activities at each stage can be made up of a mixture of the following three distinct design activity types (Lawson, 1990): information gathering, synthesis (divergent thinking) and analysis. Objectively looking at the outputs from the case studies will determine the activity type at each stage; Step 2 in figure 3.1.

3.2.1 SDPF to review the STRETCH methodology.

The STRETCH (Selection of Strategic Environmental Challenges) methodology is an approach for strategic environmental planning developed at Philips Sound and Vision as described by Cramer and Stevels (1997). Amongst other issues, Philips' environmental design pilot projects (described in section 2.4.1) highlight the need for some guidelines for systematically determining the selection of promising environmental opportunities.

The STRETCH methodology was developed for this purpose. Its objectives were: to focus on the incorporation of environmental aspects into the company's business strategy; to anticipate future environmental opportunities and threats in an earlier phase of the design process; and to achieve higher eco-efficiencies than current incremental environmental improvement methods.

The use of STRETCH at Philips Sound and Vision has contributed to 'advanced concepts' for various products including telephones, faxes and audio products (Stevels, 1998). The 'Typhoon II' monitor is one example of an 'advanced concept' taken through to production.

The STRETCH methodology consists of 5 steps which each consist of several activities, including several brainstorming sessions. The SDPF (see figure 3.2) shows the breakdown of the STRETCH methodology's 5 steps that are described in Cramer and Stevels (1997). Figure 3.2 confirms that the STRETCH methodology, in theory, focuses completely on the earliest stages of the design process: 'trigger' and 'product planning' stages.

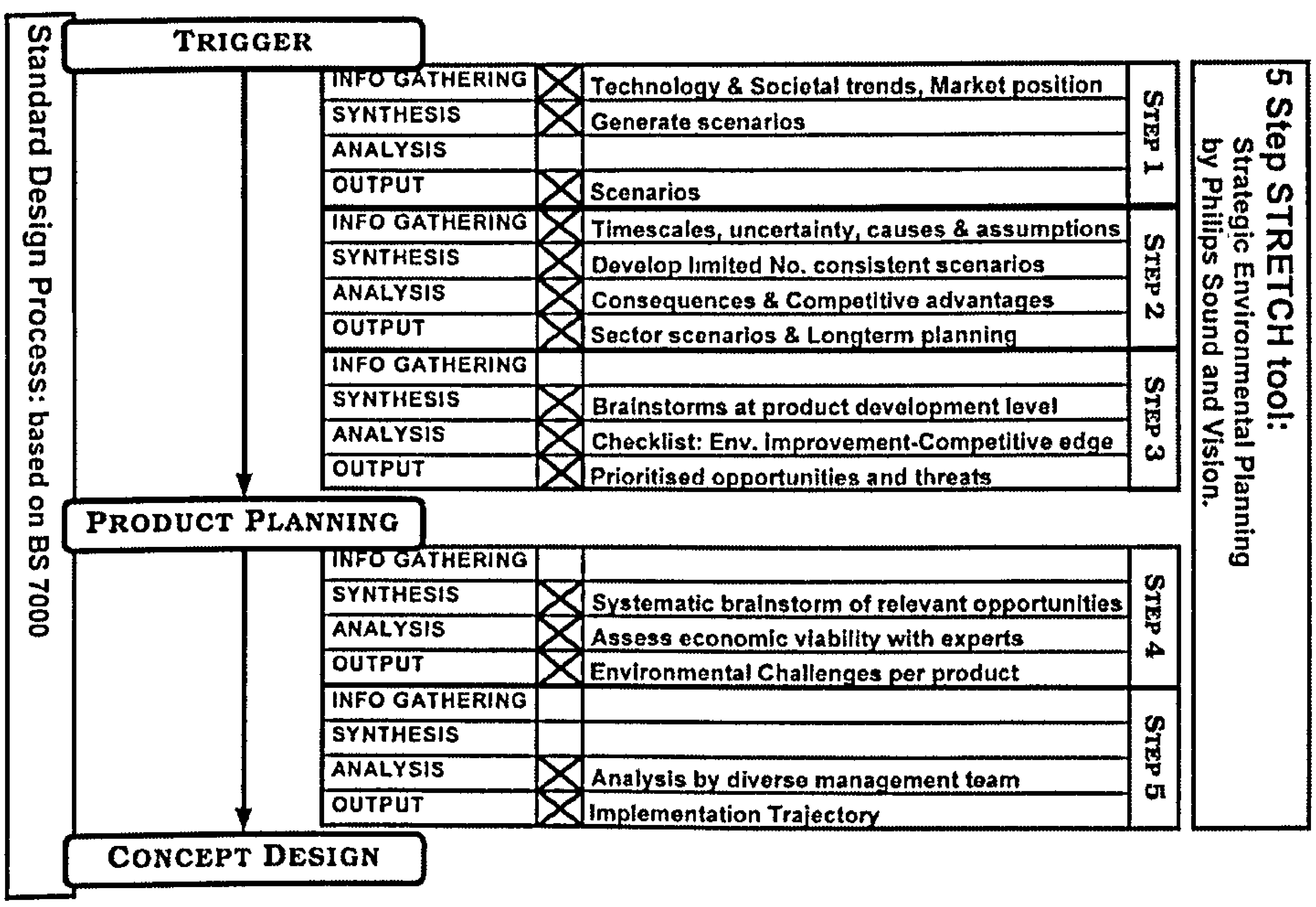


Figure 3.2: The SDPF- the breakdown of STRETCH using Cramer & Stevels (1997)

Using the SDPF in this way to analyse different tools or methods could facilitate the comparison of their intended fit within the product development process. However, 'intended fit' was not considered highly relevant for this research as the main aim is to develop tools and methodologies based on design practice rather than theory. Subsequently, the SDPF was used to look at actual ideas output from a workshop.

3.2.2 SDPF to review an eco-innovation workshop.

The project reviewed here was a collaboration between Manchester Metropolitan University, Cranfield University and a major household appliance firm and was part of the DEEDS project (Sweatman, 1997). The project's aim was to generate ideas to reduce the environmental impacts of a vacuum cleaner. Specific objectives were: to consider environmental aspects of the design at the beginning of the design process; and to work with a multi-disciplinary design team to generate concepts prior to the product specification stage.

A workshop session was held, attended by representatives from all departments of the design team. The team was introduced to the most relevant environmental impacts of an existing vacuum cleaner that had been selected for this project. Environmental impact information for the vacuum cleaner was presented in the form of an abridged LCA - shortened or simplified life cycle analysis. The four starting points for the brainstorm session were taken from the eco-compass tool (Fussler & James, 1996): reduce energy intensity; reduce mass intensity; extend service and function; design for recycle and re-use. For each starting point, two rounds of idea generation and two rounds of idea selection were held, using selection matrices from Fussler and James (1996). Seven promising ideas resulted from the workshop. The final stage of the workshop was to try to link these ideas; to embody them in a new vacuum cleaner. An evaluation session was held at the end of the workshop, which highlighted a number of points (reported in section 2.4.1) concerning the workshop's methodology.

One of the objectives for the project reported by Sweatman was to generate concepts prior to the new product specification stage. The use of the SDPF in our observations makes it clear that the actual idea output from the workshop spans across several stages of the design process. Figure 3.3 shows a few idea statements from the project.

Some of the ideas from this case study are 'compound ideas': ideas that contain ideas within themselves. For example, the idea description 'more metal components to improve perceived quality and durability' breaks down into two parts: 'improve perceived quality and durability' and 'more metal components'. These two ideas are each appropriate for different stages of the design process; 'more metal components' could be a detailed design specification for a vacuum cleaner, 'improved perceived quality and durability' could be an ecodesign project plan for a vacuum cleaner or a range of consumer products. This is illustrated in the shaded boxes in figure 3.3. Compound idea statements may obscure the most valuable aspects of ideas.

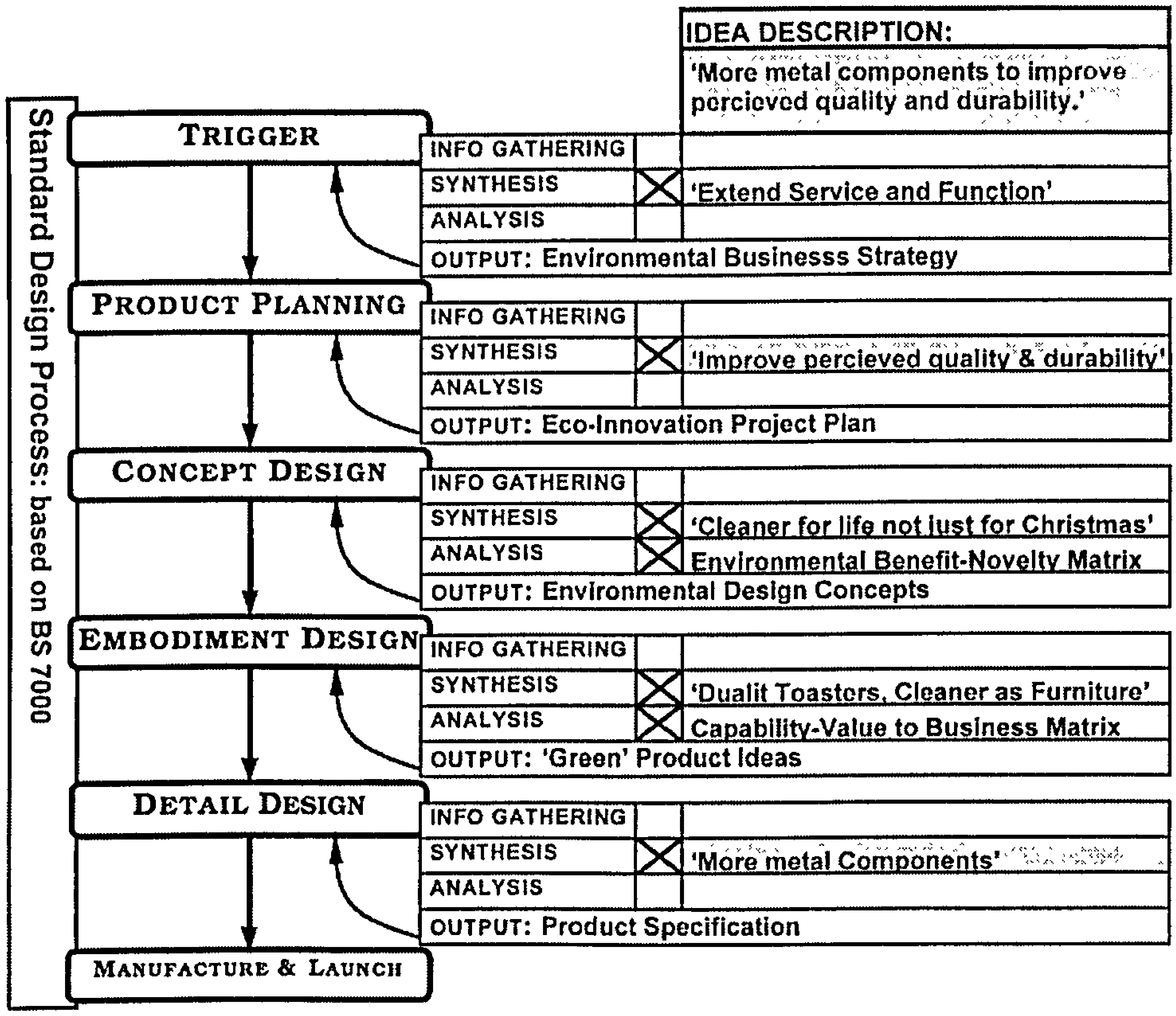


Figure 3.3: The SDPF - the breakdown of a 'compound idea' using Sweatman (1997)

Using the SDPF it is possible to separate out the ideas and make explicit where they fit in the design process. Thus the most valuable ideas may be highlighted and, if necessary, developed further in subsequent sessions. Looking at the ideas in relation to the design process can provide insights into the value of the workshop's output. This finding initiated the development of a second tool to review workshop output: the Product Ideas Tree (PIT) diagram.

3.3 Product Ideas Tree (PIT) diagram

The Product Ideas Tree (PIT) diagram was initially developed as a compact way to review the ideas resulting from creative eco-innovation workshops. The PIT diagram can record *all* ideas generated in these workshops whilst simultaneously mapping them onto the stages of the design process. The PIT diagram was synthesised from elements of the SDPF, Mind Maps (Buzan & Buzan, 1995) and starting points from environmental design tools such as the Life Cycle Design Strategy (LiDS) wheel (Brezet & Van Hemel, 1997) and the eco-compass (Fussler & James, 1996).

Figure 3.4 explains the different elements that make up the PIT diagram. The radial idea-recording technique is similar to the Mind-mapping techniques developed by Buzan and Buzan (1995). The nodes represent the ideas statements recorded. The statements are linked and clustered as idea branches. The 'starting points' of the PIT diagram were drawn from the eco-compass or the LiDS-wheel, (e.g. Reduce energy intensity, Design for recycle and reuse). The labels on the 'rings' come from the standard design process model (e.g. concept design, embodiment design).

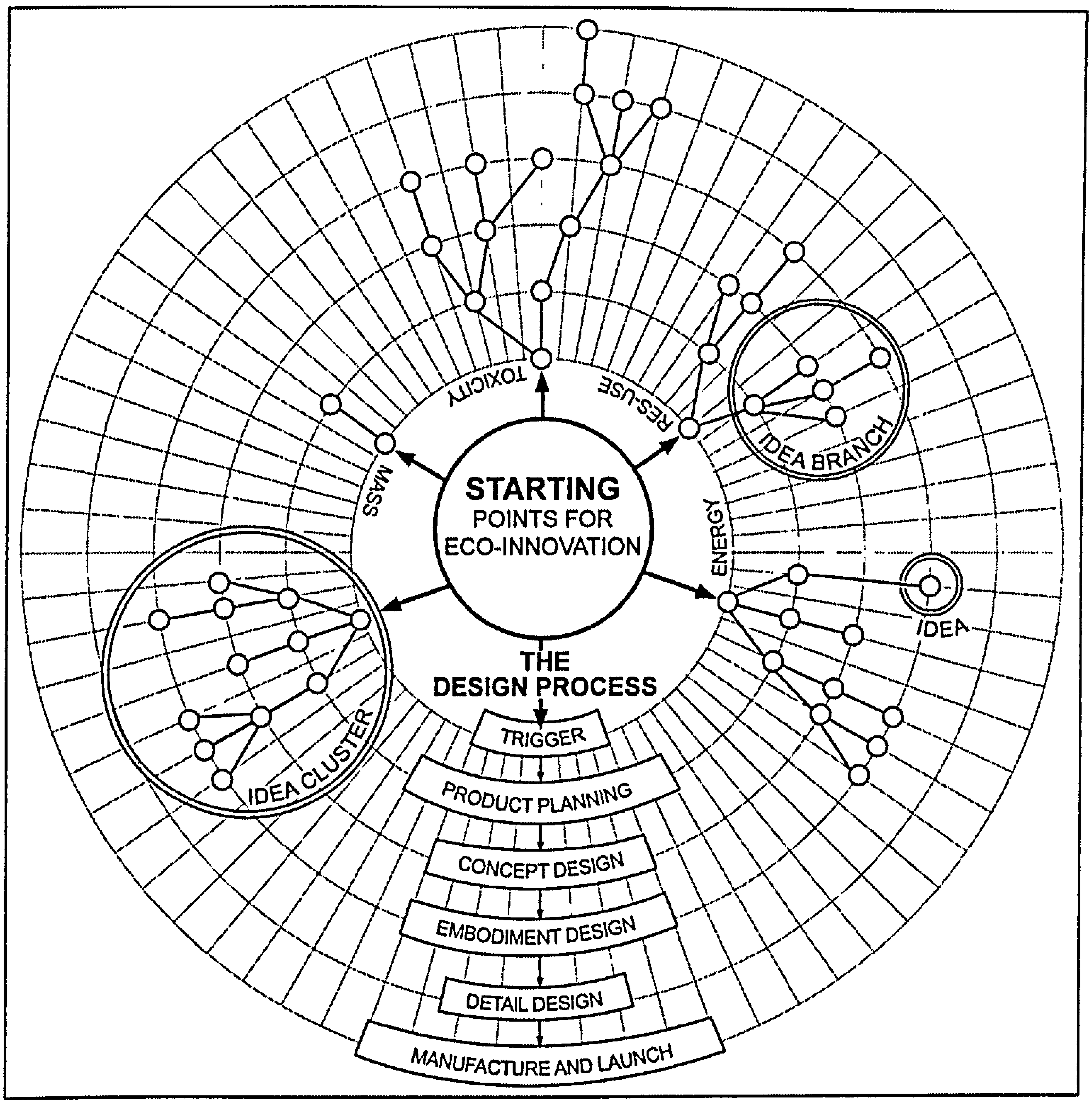


Figure 3.4: PIT diagram explaining its elements

Using Mind Maps to record output from eco-innovation workshops.

Traditionally, ideas are recorded in the form of linear lists. Buzan and Buzan (1995) state that listing ideas opposes the working of the mind, in that it cuts ideas off from the ideas preceding and following it. They developed Mind Maps as a better way to generate and record ideas. Mind Mapping is now a well-established radial recording technique and a powerful graphic representation of ideas. Figure 3.5 shows how every key word or image added to a Mind Map adds the possibility of a new and greater range of associations, which in themselves add the possibilities of new and greater ranges: ad infinitum. The Mind-mapping technique does not define a hierarchical structure.

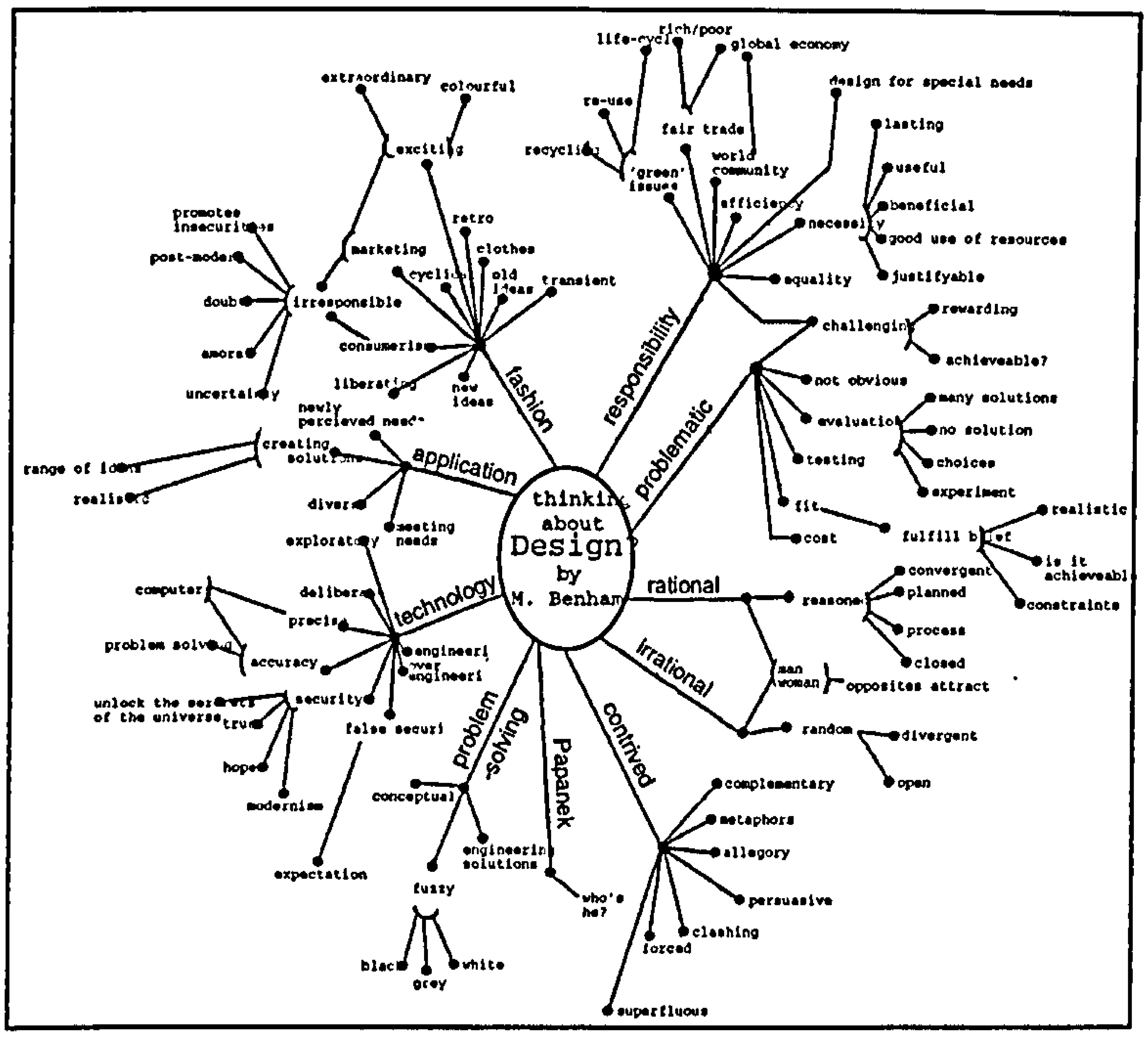


Figure 3.5: Example of the Mind-map recording technique

Using a Mind Map type representation could provide a way to get an overview of the raw ideas output from eco-innovation workshops.

'Starting points' from the eco-compass and the LiDS-wheel methods.

The eco-compass (Fussler & James, 1996) and the LiDS-wheel (Brezet & Van Hemel, 1997) are two of the more successful streamlined environmental design tools.

The eco-compass was designed to condense environmental data into a simple model which would assist in the integration of environmental issues within the business decision process. The compass has six poles or 'axes', which are intended to represent all significant environmental issues: mass intensity, reducing human health and environmental risk, energy intensity, re-use and revalorisation of wastes, resource conservation and extending service and function.

The eco-compass is normally used as a comparative spider diagram. Figure 3.6 shows how new options or designs are compared against the original design or 'base case'. The original product or 'base case' scores 2 on each axis. The new design option is scored better or worse on each axis according to score table devised. By joining up the scores a visual representation is given of the new option's potential improvements. Using such diagrams assists the business decision process by providing a quick method of comparing several new options or concepts.

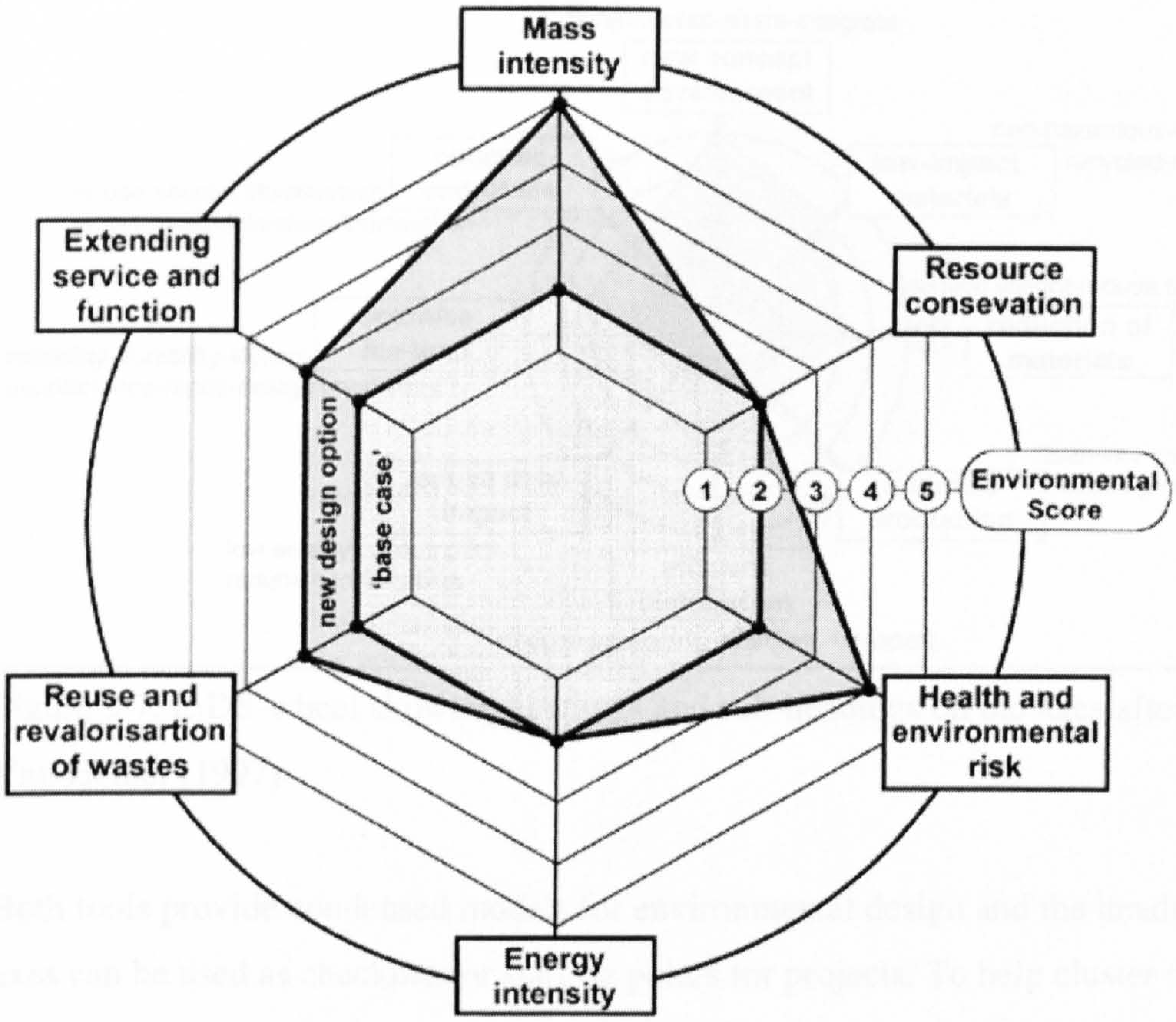


Figure 3.6: Eco-compass showing its elements after Fussler and James (1996)

The LiDS-wheel is another tool that was developed as a streamlined environmental design tool. The environmental design guidelines are clustered on the eight 'axes'. Clockwise, the axes of the LiDS-wheel follow the sequence of the product life cycle: new concept development, low impact materials, reduction of materials, optimisation of production techniques, efficient distribution, reduction of impact in the use phase, optimisation of initial life-time and optimisation of end-of-life system.

The LiDS-wheel can be used to draw comparative visual maps similar to the eco-compass. However, the LiDS-wheel is different from the eco-compass, as it is intended to help prioritise design strategies for products. The comparative diagram is used to compare different design strategies instead of new product concepts. The LiDS-wheel also provides a great overview of options for improving products throughout their life cycles by providing the guidelines or sub-headings shown in figure 3.7.

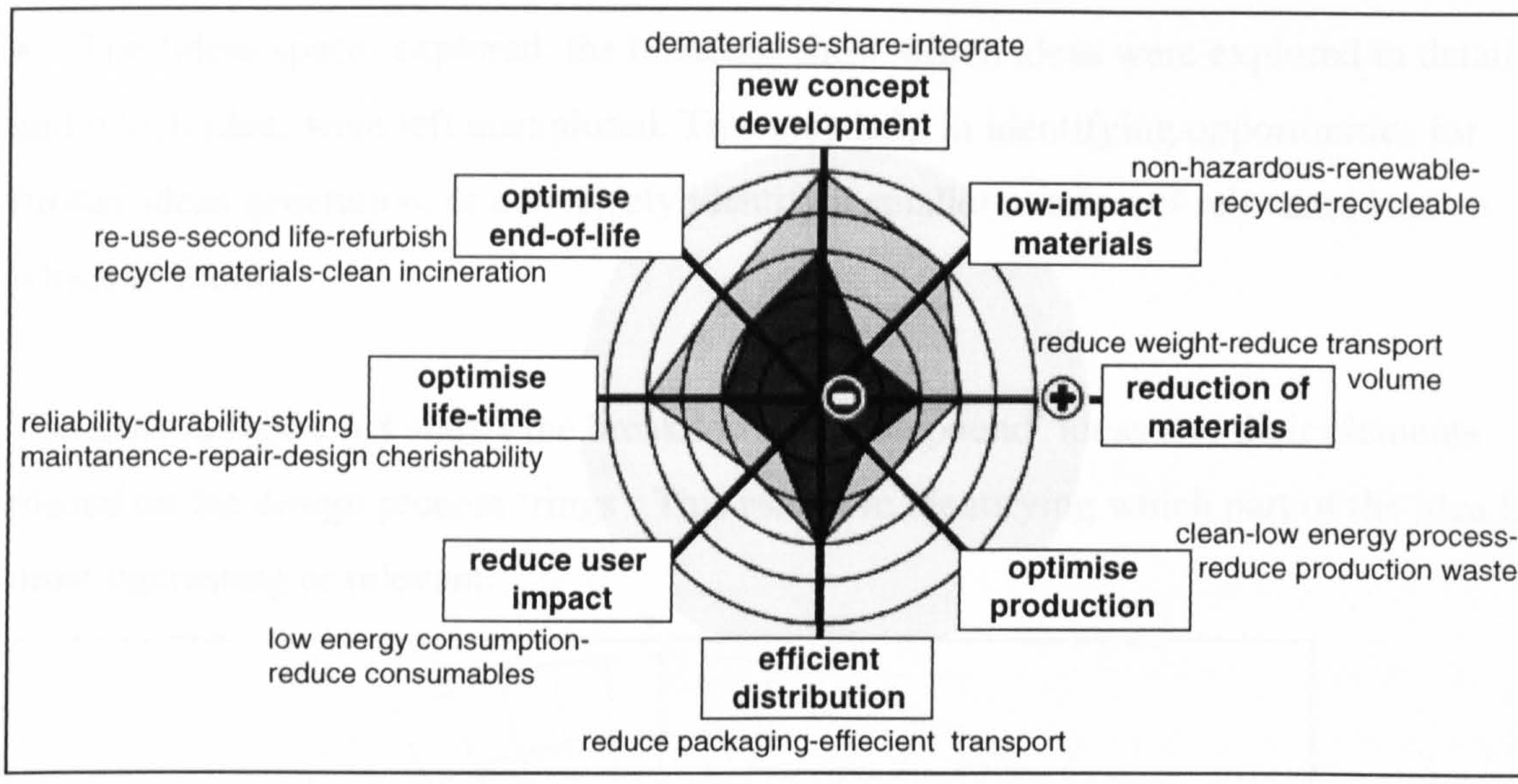


Figure 3.7: LiDS-wheel showing headings and sub-headings on the axes after Brezet and Van Hemel (1997)

Both tools provide condensed models for environmental design and the headings on the axes can be used as checklists or starting points for projects. To help cluster the ideas output from the case studies in Sweatman (1997) and Jones et al. (1999), it was possible to use some of the headings or 'axes' from the eco-compass and LiDS-wheel on the inner ring of the PIT diagram as shown in figure 3.8.

3.3.1 PIT diagram to review an eco-innovation workshop.

In section 3.2.2 the author reviewed *where* the ideas resulting from the workshop cited in Sweatman (1997) fit within the design process using the SDPF. Using the SDPF in this way, ideas cannot easily be clustered according to the environmental strategies which they address. Using the PIT diagram, ideas are categorised according to their relevance to stages in the design process (as in the SDPF diagram) *and* their relevance to environmental strategies (taken from the eco-compass and LiDS-wheel) as shown in figure 3.8.

Using the PIT diagram in this way shows:

- The quantity of ideas recorded: each node on the diagram represents one idea.

- The span of ideas explored: each cluster of branches on the diagram represents a brainstorming topic during the workshop. This overview may help participants see their contributions in relation to 'the bigger picture'.
- The 'ideas space' explored: the branches show which ideas were explored in detail and which ideas were left unexplored. This may help in identifying opportunities for further ideas generation, or conversely identify a smaller number of relevant ideas on which to focus.

The inset in figure 3.8 shows the breakdown of 'compound' ideas and their elements placed on the design process 'rings'. This assists in identifying which part of the idea is most interesting or relevant.

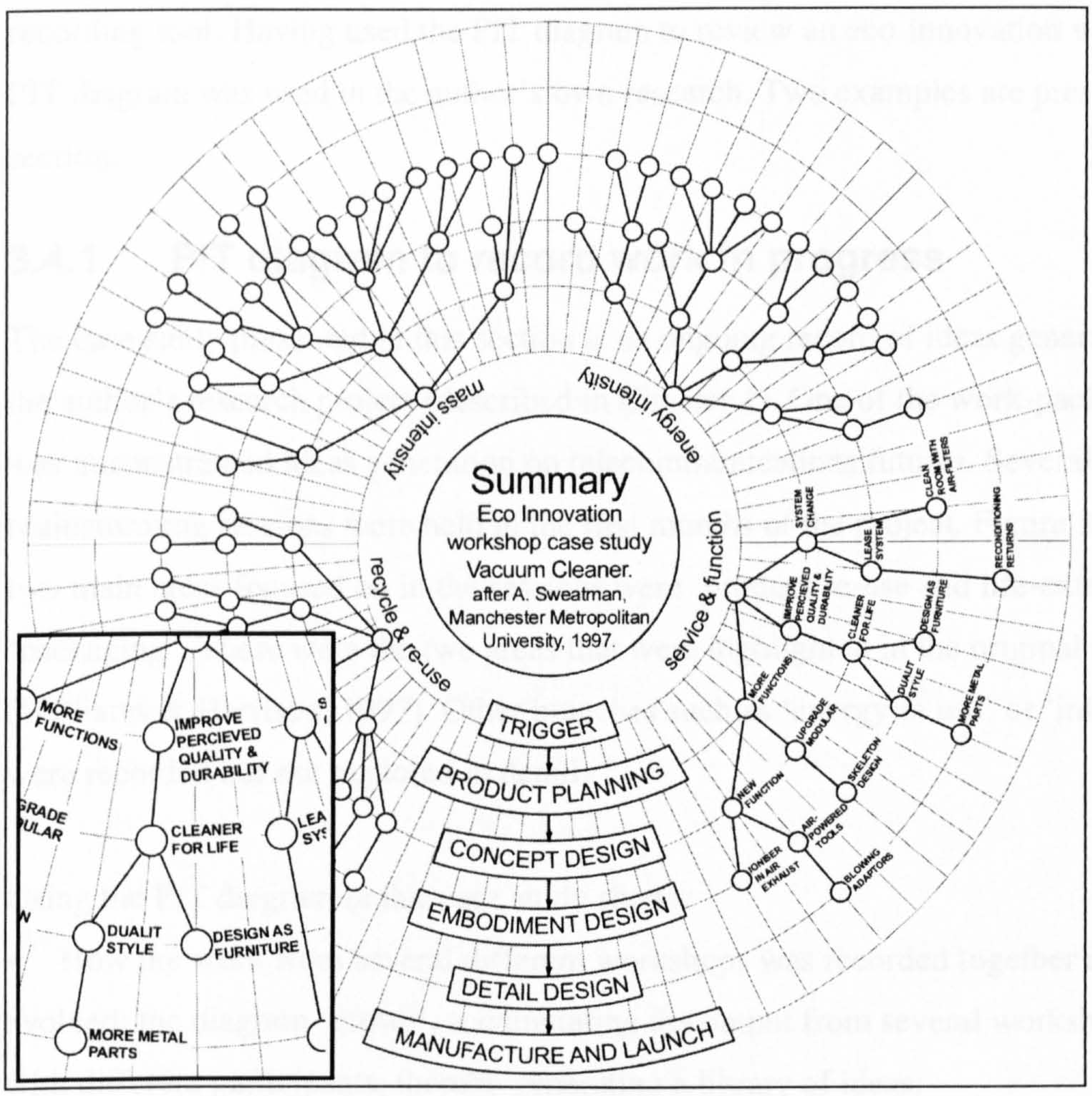


Figure 3.8: PIT diagram shows 'ideas space explored', inset shows breakdown of 'multiple ideas' using Sweatman (1997)

Analysing the outputs from eco-innovation workshops, using either the SDPF or the PIT diagram, suggests that ideas generated in the creative sessions tend to span across all stages of the design process. The SDPF helps to identify 'compound' idea statements which may be obscuring the most valuable aspects of the ideas generated. The PIT diagram provides an overview of the outputs from eco-innovation workshops. The PIT diagram may provide valuable documentation to facilitate the communication between participants in the design process.

3.4 Developing the PIT diagram as a recording tool

This section explains how the PIT diagram evolved from an evaluation tool to an idea-recording tool. Having used the PIT diagram to review an eco-innovation workshop, the PIT diagram was used in the author's own research. Two examples are presented in this section.

3.4.1 PIT diagram to record work in progress

The case study presented in this section is an ongoing record of ideas generated within the author's research project (described in Chapter 1). One of the work-packages defined was unconstrained ideas generation on telecommunications futures. Several different brainstorming sessions were held in the first months of the project. Figure 3.9 shows the two main areas focused on in the sessions were 'product re-use and life-extension' and 'packaging'. These were the two areas that were highlighted in the original project brief (Williams & Harrison, 1997). Other branches such as 'energy in use' or 'infrastructure' were recorded but not explored in detail.

Using the PIT diagram in this case study shows:

- How the work from several different workshops was recorded together as the project evolved: the diagram 'grows', accumulating the output from several workshop sessions with different participants, thereby generating a library of ideas.
- Copies of the diagram were proven useful in research meetings; facilitating the discussion of ideas. The inset in figure 3.9 shows some note-taking during the discussion of ideas.

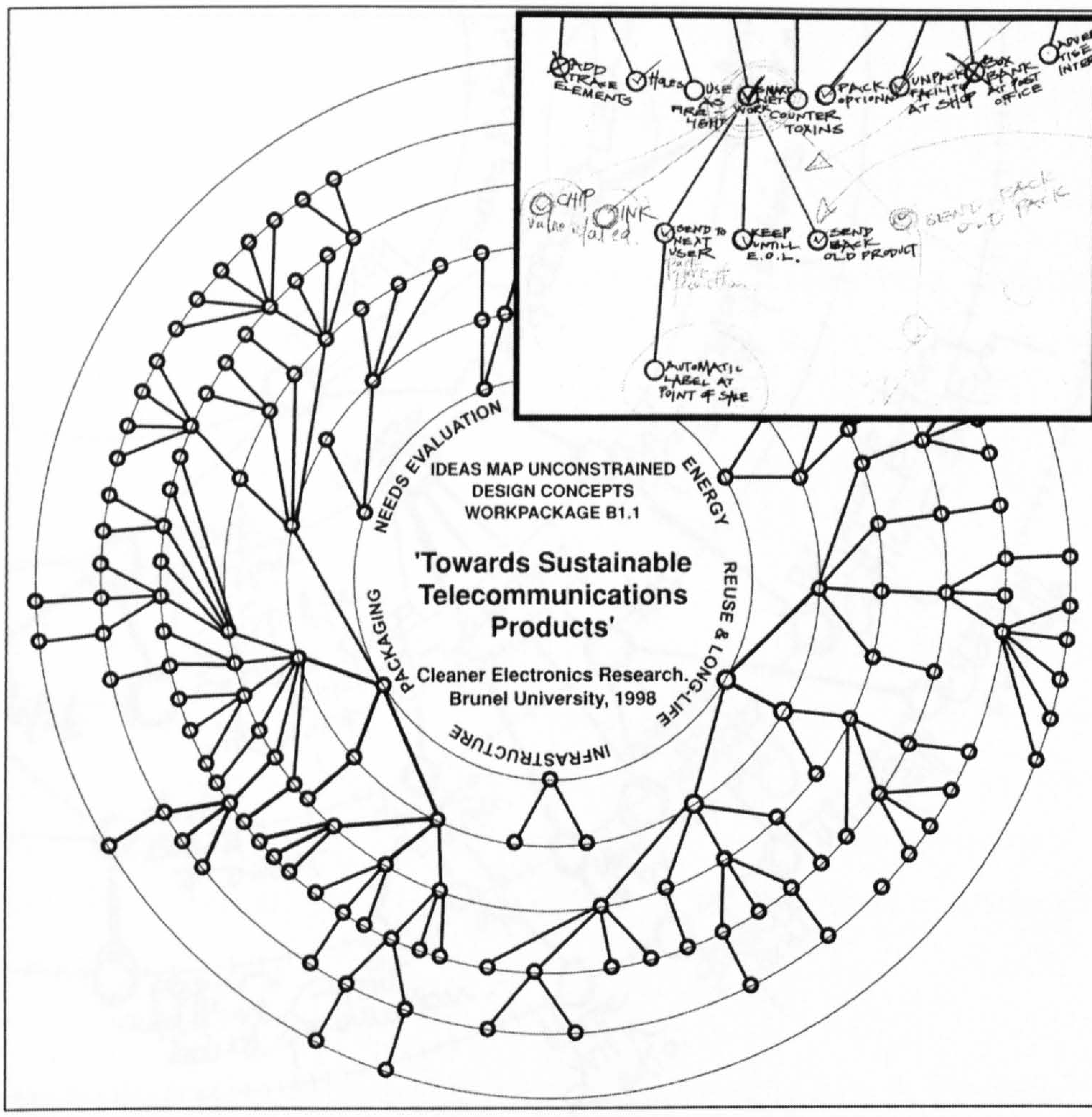


Figure 3.9: PIT diagram shows ideas from several workshop sessions, inset shows note-taking during the discussion of ideas

3.4.2 PIT diagram as a 'live' recording tool

Blank templates of the PIT diagram, with only the rings of the diagram marked, were prepared for use during workshops. The person appointed as the 'recorder' for this brainstorm session used these blank templates. At high speed, the recorder made notes on the diagram linking the relevant ideas and starting new branches when necessary, as shown in figure 3.10. The recorder also facilitated the session by steering the brainstorm to areas unexplored on the diagram.

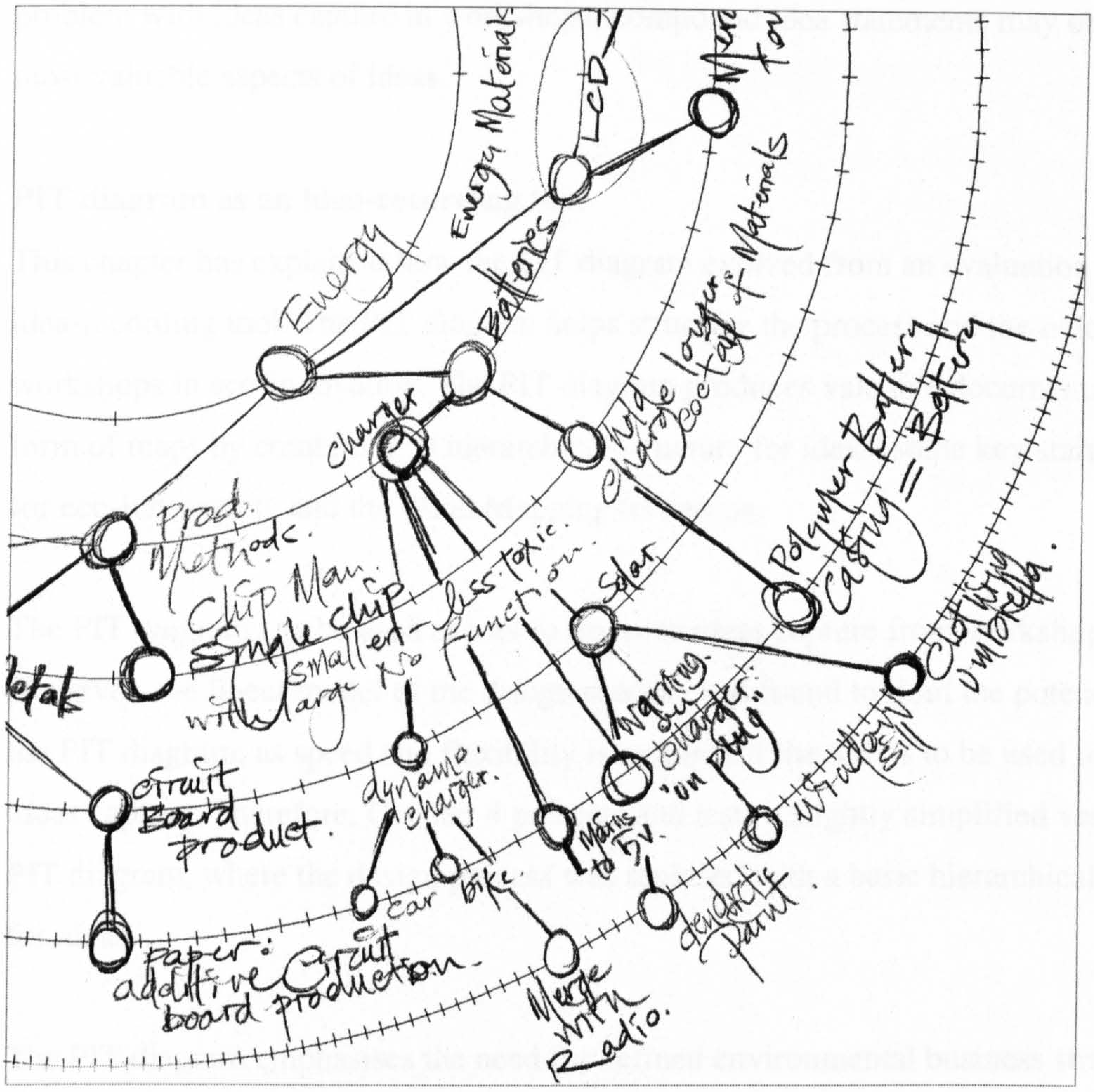


Figure 3.10: PIT diagram template showing notes taken during a brainstorm session

The use of the PIT diagram in this workshop demonstrated several points of potential value. The application of the PIT diagram during live creative sessions could help:

- to explain the starting points for a brainstorm in a briefing session;
- to indicate the type of ideas output desired: strategic, conceptual or detailed ideas;
- to give all participants a distinct sense of achievement from the workshop. A comprehensive computer-generated diagram could be circulated afterwards.

3.5 Conclusions

The evaluation tools helped to review the output from workshops in further detail. The most important conclusion from their use is that the idea output from workshops spans across several stages of the design process. The evaluation tools highlighted another problem with ideas capture in workshops; compound idea statements may obscure the most valuable aspects of ideas.

PIT diagram as an idea-recording tool

This chapter has explained how the PIT diagram evolved from an evaluation tool to an idea-recording tool. The PIT diagram helps structure the process and the outcomes from workshops in eco-innovation. The PIT diagram produces valuable documentation in the form of maps by combining: a hierarchical structure for ideas, some key starting points for eco-innovation, and the Mind Mapping technique.

The PIT diagram can be used as tool to improve ideas capture from workshops. However, the linear model of the design process was found to limit the potential use of the PIT diagram, as speed and flexibility is required if the tool is to be used to improve ideas capture. Therefore, Chapter 4 presents and tests a slightly simplified version of the PIT diagram, where the design process was replaced with a basic hierarchical structure for ideas.

The PIT diagram emphasises the need for defined environmental business strategies as they provide the key-starting points on the inside ring of the diagram. A PIT diagram with such key-starting points can be used in workshops to generate ideas that radiate across the whole surface of the diagram, thereby potentially providing a greater span of environmentally relevant ideas.

The PIT diagram aims to overcome some of the communication problems between the different participants (designers, managers, engineers and marketing specialists) at the early stages of the eco-innovation process by presenting each participant's contributions in relation to the 'bigger picture'.

Chapter 4 Testing the PIT diagram

This chapter reports on the controlled workshop experiment that was conducted to test and verify various aspects of the PIT diagram. This research focuses specifically on the workshop-style activity within the environmental design process. Chapter 2 established that relatively little research has been done on the idea-generation process within environmental design. When tools or methods have been used, their effectiveness has not been tested or analysed and there are no examples of workshops conducted in a controlled environment.

This chapter reports on the use of the PIT diagram in an experiment where the participants were asked to generate ideas for improving domestic dishwashing. The aims of the experiment were: to establish which attributes of the tool were most beneficial in the workshop session; to make suggestions for the further development of the PIT diagram; and to provide insights into better ways of testing such a recording tool.

4.1 Structuring workshop activities and outcomes

The review of workshops in Chapter 2 established that to get the most out of idea generating workshops, the *activity* and the *outcomes* need to be structured and the outcomes need to display the potential to be integrated in business. When used as a recording tool the PIT diagram is intended to structure both the process and the outcomes from workshops in eco-innovation by combining: some key-starting points for eco-innovation; a hierarchical structure for ideas; and the Mind Mapping technique.

Much work has been done on the *activity* of idea generation, and many techniques have been developed and established such as: Brainstorming (Osborn, 1963); Lateral Thinking (De Bono, 1970); and Synectics (Gordon, 1961). Many of these generic Creative Problem Solving (CPS) techniques have been applied in design workshops. Generally, these techniques aim to increase the productivity of participants by controlling the direction and quality of their thoughts (Lawson, 1990). However, the original authors place relatively little emphasis on structuring the *outcomes* from their techniques. Osborne suggests appointing a secretary to take down and consecutively number all ideas during a session. De Bono (1992) briefly discusses the different methods of capturing ideas during the idea generation process and the need to extract and record the output systematically. He uses a checklist to group the ideas and proposes a classification technique to formalise different types of output.

Owen (1992) developed hierarchical and clustering information structures that enabled design teams to represent the information needed in workshop sessions. His hierarchical structures record all the different functional levels at which the system - to be designed - should perform. This hierarchy provides a function structure to stimulate innovative solutions.

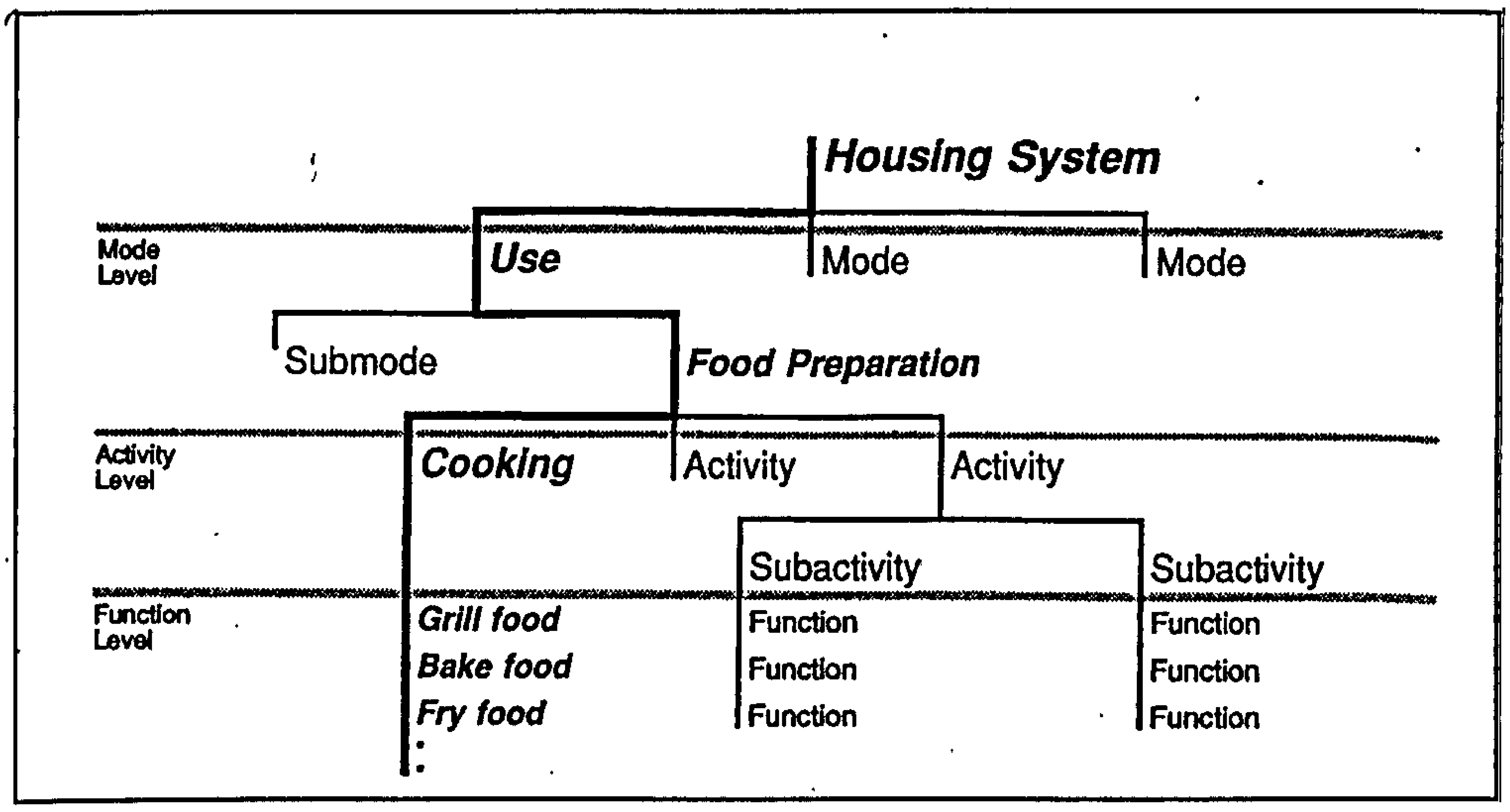


Figure 4.1: Hierarchical function structure after Owen (1992)

Owen's research (1992) stresses that the way information is collected and organised in a project is crucial to the creative quality of the result. During a project, information should be organised so that ideas can be merged, modified and expanded. Design teams can use his information structures to organise the (synthesis) idea-generation activity. He suggests ways in which creative ideas can be stimulated at different levels of the function structure, but does not report the outcomes from such team sessions.

4.1.1 Research in Environmental Design

Previous authors have developed tools and methodologies to improve creative or early stages of environmental design (Sherwin, 2000; Benjamin, 1994; Street, 1997), however very few have conducted systematic analysis of their contributions.

Benjamin's thesis (1994) presents some of the early research work on environmental design tools. His work explores the issues behind creating environmental design tools and how they might be developed. He proposes three different tools / methodologies based on his findings: an ecodesign checklist, an educational poster supported with HyperCard stacks, and a HyperCard software tool. The software tool was outlined but not prototyped and none of the proposed tools were systematically tested.

Sherwin (2000) made a significant contribution to research for early stages of environmental design. He did not propose a specific tool or methodology as such, but his contributions were to the epistemology, knowledge, understanding, and the integration of environmental design into industry. He investigated the process of innovative eco-design using a qualitative approach to analyse a single case study. He considered applying protocol analysis, (a quantitative research technique popular in mainstream design research, see section 4.2.3), but decided that a controlled laboratory-type experiment would not be flexible enough to provide insights into the integration into industry of environmental design.

Street (1997) conducted a scenario workshop on 'sustainable futures for urban living' but did not conduct a full evaluation of the environmental outputs and suggestions. She admits that in order to draw conclusions on the effectiveness of the workshop's method – the participatory process - detailed observation of interactions and analysis of dialogue during the workshops would be required.

One exception where empirical analysis was conducted is from Poyner and Simon (1997). In this study they investigated the validity of their newly prototyped computer aided ecodesign tool (the EPDS agent). They looked at whether prior knowledge was needed to set priorities correctly within their software, and whether the tool helped resolve the higher priority issues, early in the design process. They conducted controlled experiments which were recorded on video and analysed using the protocol analysis method from mainstream design research (Cross, Christiaans & Dorst, 1996). This testing of their tools led to many more insights into their new tool besides the tested hypotheses. There were clear directions for further work, its integration into practice and its integration with other computer aided design (CAD) tools.

In mainstream design research, quantitative analysis of the design activity, methodologies or tools is much more common. Several commonly held beliefs have been investigated and confirmed or dispelled. This type of design research has been developing over the last three decades. The next section looks at some of issues considered in the design of the study reported in this chapter.

4.2 Testing tools and methodologies.

Design researchers have found that the take-up of proposed tools and methods has often been disappointing (Stempfle and Badke-Schaub, 2002; Cross, 1994). The limited take-up of new tools and methodologies in practice has led to calls for non-intrusive tools that can be more easily integrated into existing practices. But perhaps more importantly, it has been recognised that tools need to be based on research of actual practice. This is one of the reasons why design research has become more prevalent in recent times.

Cross, Christiaans and Dorst (1996) have each made significant contributions to design research. They are interested in empirical design research but admit that it is still a difficult subject to capture. The generic driver for empirical studies in this field is the growing interest in analysis of the design activity which is stimulated by the recognition of the value of design ability.

There seem to be two approaches in this design research. The first approach is one where design in practice is studied, problems are identified, and finally, tools or methodologies can be suggested based on firm research findings. The second approach is one where tools and methods are still suggested in the existing way, but the new tools are tested using empirical research. Subsequently, the new tools often go through an iterative improvement process.

4.2.1 Empirical studies of design to inform the development of new tools

This section summarises some of the empirical studies of design practice relevant to the PIT diagram experiment.

Stempfle and Badke-Schaub (2002) describe three strains of design research: the normative or theory-building strain; the empirical strain looking at actual practice; and the reflective strain - in which design is seen as art-in-practice. Practitioner-centred tools and methods based on empirical research of practice are bound to be more effective than those based on theory-building models. Studies that include empirical research contribute to the body of knowledge still lacking in design. Further in the future, beyond good practitioner-centred tools and methodologies, they say that design research must be encouraged towards the reflective strain of research.

Valkenburg (2000) set out with the goal of providing tools and guidelines to improve team designing. Her view was that design research should inform the development of those new tools and guidelines. Her approach was to first understand 'team designing' and identify problems. She found that there was still a shortage of understanding of the team process itself. Her work makes a significant contribution to that understanding but she emphasizes that this work focusing on designing as practitioners' experience is not complete.

The problem with these approaches is that the empirical studies of design practice could perhaps never be considered complete or conclusive. For eco-innovation there are more merits in the second approach where tools and methods are suggested and subsequently tested. Good design research is able to offer qualitative insights into the ease with which tools and methods are used, as well as quantitative data for comparative analysis of the tools and methods' performance (Stanton & Stevenage, 1998). This thesis adopts the second approach: two novel tools are proposed; the subsequent testing of those tools contributes to the body of knowledge in design research.

4.2.2 Proposing new tools and subsequent testing

Some examples from mainstream design research were found where tools or methods have been proposed and subsequently tested to inform their further development (Snoek & Hekkert, 1998; Van Der Lugt, 2000; Pasman, 2002).

The study that is closest to the investigations carried out in this chapter is that by Van Der Lugt (2000). He proposes a methodology for use in workshops based on sketching and subsequently tests this proposed tool. The specific hypothesis that Van Der Lugt (2000) investigated was that sketching in workshops would stimulate participants to build on each other's ideas more and thereby improve the outcomes from the workshops. He studied different ways in which participants build on each other's ideas and found that workshops *not* using sketching performed better in most of the aspects measured. The workshops with best performance were the ones producing sentential output. He concluded that the use of sketching perhaps has a different role to play, at a later stage to interlink and visualise ideas. He suggests an altered version of his tool.

A major contribution to knowledge in design research from Van Der Lugt's work (2000) is the development of a method to investigate the different types of links amongst the ideas generated in workshops. He was able to measure the extent to which the participants were building on each other's ideas. His measurements – 'link-indices' - said something about the effectiveness of the process and more specifically about the practicipants' collaboration based on the ideas statements themselves.

Van Der Lugt's study confirmed the decision in this thesis to steer away from sketching output and encourage sentential output in the form of simple ideas statements to study the proposed tools. The participants in the PIT diagram experiment were asked to transcribe sketches into idea statements. Although his 'link-analysis' was successful, it would have been too complex and time-consuming for the purposes of analysing the PIT diagram. The ideas statements he took from the protocol were similar to the ideas statements judged and counted in this chapter. The PIT diagram experiment does look at the interactions between participants, but does not use the ideas statements for that part of the study.

4.2.3 Practical aspects of design research studies

This section summarises some of the practical aspects of design research that informed the PIT diagram experiment. Table 4.1 brings together some recent studies in design research and compares the experiments' designs, types of tasks set, data analysis methods and types of conclusions drawn.

	Experiment Design, teams and participants	Task or Assignment design	Data analysis	Notes, outcomes and conclusions
Van Der Lugt, 2000	Used a typical workshop set up: 4 participants and a facilitator. Conducted the same workshop experiment with 4 teams, varying the person recording (participants or facilitator) and the medium of recording (sketches or statements)	The assigment was taken from a previous design research study but streamlined to a brief problem statement.	Investigated the role of sketching in workshops to stimulate participants' collaboration. He looked at different types of data : quality of process & ideas generated; satisfaction of participants; and extensive protocol analysis of output.	He used a novel analysis technique to investigate the links amongst the ideas generated as a measure of collaboration. The workshops using sentential output were more effective; sketching may have a different role to play at a slightly later stage.
Dorst, Christiaans and Cross, 1996	A 2 hr. workshop was conducted by both lone designers and teams of three. Conditions were controlled. 20 researchers compared their analyses of the same workshop data in order to discuss the use of protocol analysis in design research.	A long task description was developed, a trial run of the assignment was conducted before the experiment. Factors considered: realism, abstraction, ambiguity, identifiable opportunity, familiarity, target market sector, info sources, duration.	The 2 most interesting experiments (out of 5) were selected. Researchers were to look at 'understanding the design process'. Video recordings and transcribed protocols were sent to the researchers 6 months before their presentation meeting.	Protocol analysis was proved useful for design research. Reservations were: may not capture all mental processes, lots of interpretation needed when looking at data; seeks a balance bertween its rigour and relevance of results to design practice.
Stempfle , Badke-Schaub, 2002	Three similar teams of engineering designers worked on the same assignment for one day in the same controlled workshop environment. They were free to tackle the process in any way	Teams were given a complex design task with extra information available during the workshop such as specifications, technical information, materials. They interacted with a customer (simulated), 3 times during the workshop.	Protocol analysis was used to look at the following aspects of team communication: the order of occurrence of different design steps; frequencies of different communicative acts; the transitions between design steps.	The output from the workshop was broken into statements. The occurrence of design steps throughout the whole workshop provided insights the collective design process. The 3 groups each employed different strategies, contrary to existing design theory.
Valkenburg and Dorst, 1998	2 out of 9 multi-disciplinary teams competing in a student design competition were selected based on the similarity of their 4 team members' skills mix. The first 2 days of an 8 day event was recorded: the concept design stage.	The assignment was a simple description; to build a smart product (robot) to perform a specific task. First the teams had to establish the concept, which was presented to experts at the end of the first 2 days.	Content anylsis of the verbal protocol was conducted based on theory of reflective practice. Checked recognition of the coding categories. The protocol text was marked in bold at interesting stages. Sub-functions of design task recorded as parallel streams.	The first time reflective practice had been used to investigate effectiveness of design teams. The team that worked in a 'reflective way' performed much better than the team that 'muddled through'. Reflecting is important in team designing.
Snoek and Hekkert, 1998	30 individual design students took part in a 2-stage experiment: preparation stage 3 days at home; experimental session 3 hrs. in controlled setting. Half the group was stimulated to use a 'context' as a starting point for their design.	The participants were individually briefed, the experimenter explained the design problem and gave out a written version to take home. Task: 1st stage to gather sufficient information, 2nd stage generate 2 concepts for a future product.	This was not a protocol study. Different types of data were recorded in the form of work diaries, questionnaires, recorded interviews, and the design sheets themselves. The design sheets were marked on 10 different criteria by 10 judges.	Investigated whether giving designers a novel context as a departure point for their design would generate more innovative designs. The 'directing strategy' was validated: it is possible to direct designers toward more creative/innovative solutions.

Table 4.1: Practical aspects of recent design research studies

There are three main research techniques commonly used in design research practice today: retrospective reports and interviews; observation and diary keeping; and various types of protocol analysis. Reports, interviews, observation, diary keeping are mainly used in field studies, whilst protocol analysis is currently the most popular tool for empirical studies in controlled design experiments.

Although practice in the field may be different from the controlled workshop experiments, authors can usually justify their approach. Valkenburg and Dorst (1998), for example, say designers in the field work on different projects in parallel making accurate recording of data very difficult. They justify the use of their controlled workshop study to enable the recording of rich data that spans the design process whilst providing a reasonably realistic context.

Protocol analysis

Protocol analysis is also referred to as content analysis, and is a technique from psychological research to aid the quantitative content description of recorded communications. The protocol -record of experimental observations - is split into manageable chunks, which can then be coded according to concept categories that are relevant to the research questions. These concepts may be identified in words, phrases, sentences, or themes which are then counted – coded - in the protocol. The simplest form of content analysis looks at the existence and frequency of concepts in a text and does not look into the relationships amongst the concepts in a text. Protocol analysis is a popular technique due to its flexibility; researchers devise their own scoring and coding procedures according to the nature of their investigation. Protocol analysis enables quantitative, statistical studies without losing touch with the content of the subject.

In their introduction Cross, Christiaans and Dorst (1996) explain the evolution of the methodology for design research. Protocol analysis has been used in several ways in design research: single subject studies, two or more collaborating participants and, more recently, to look at the activity of 'team designing'.

In this chapter protocol analysis is used in three ways, first, to count the idea statements and judge the environmental relevance of them. Secondly, the interactions between participants are analysed using direct content analysis of the video recordings, without a fully transcribed protocol. And additionally, a novel version of content analysis was conducted on the picture boards from the warm-up exercise. In other words this experiment looks at three different types of recorded communications: the written idea statements; themes in the video recordings; and pictures selected by the participants.

Reliability checks

Protocol analysis suffers from the same reliability problem as other research methods: reproducibility of the experiment (Palmquist, 2002). In protocol analysis, reproducibility can be improved by defining accurately the categories that define the concepts, and by developing rules that allow others to code the same data. The robustness of the study is often checked by performing an 'inter-observer reliability check', in which a second researcher codes a section of the protocol according to the rules developed (Valkenburg, 2000; Van Der Lugt, 1999; Dorst & Cross, 2001; Snoek, Christiaans & Hekkert, 1999).

Reliability of the method has been a topic for discussion in design research since its increased use and popularity. The Delft Protocol workshop held in 1994 (Dorst, Christiaans and Cross, 1996) was entirely aimed at discussing the methodology and agreeing on some general procedures or standards for protocol analysis in design research. Other ways to increase the reliability of the data analysis have been to use more than one scorer and use their agreed or averaged assessments of the data (Stempfle and Badke-Schaub, 2002; Snoek, Christiaans & Hekkert, 1999).

4.3 Simplifying the PIT diagram

Chapter 2 established that tools and methods for environmental design might be too complex, may slow down the design process or even limit the level of innovation. This research intends to overcome these problems by proposing two simple tools that can be applied in the early stages of the design process to assist different participants. Workshops facilitated with simple tools should enable participants to learn and adopt environmental design through practice.

Chapter 3 established that the linear model of the design process proved to be limiting when the PIT diagram was used as a recording tool. Stempfle and Badke-Schaub's (2002) extensive research on team communication in the design process supports this finding. Their work shows that if the ideas statements are classified according to the labels of design process stages, no characteristic agglomeration of them could be detected at any particular stage of their workshop experiment. Valkenburg (2000) gives a historical view of why the linear model of the design process has been largely abandoned for studying design in practice. Around the mid 80's several authors conducted studies on the difference between prescriptive models and actual design practice. These studies showed that 'the compartmentalisation of the design process' was unrealistic.

The research by Valkenburg (2000),Stempfle and Badke-Schaub (2002) has helped explain why the design process labels on the rings of the PIT diagram were not so useful in practice. The design process labels on the rings were dropped and a simpler version of the PIT diagram is proposed for testing. The rings still provide a basic hierarchical structure for ideas, but one which is more flexible in use. This simplified version of the PIT diagram was developed with the help of a designer experimenting with different ways of using the rings in his projects. Figure 4.2 shows one of the developmental versions of the PIT diagram where the designer defined the rings in a totally different way.

Figure 4.2: Developmental version of the PIT diagram after Coombes (2001)

Figure 4.3 shows a schematic of the simplified PIT diagram tested in this chapter. The pointers explain the way it is intended to be used. The key-starting points for eco-innovation used in this experiment are also shown.

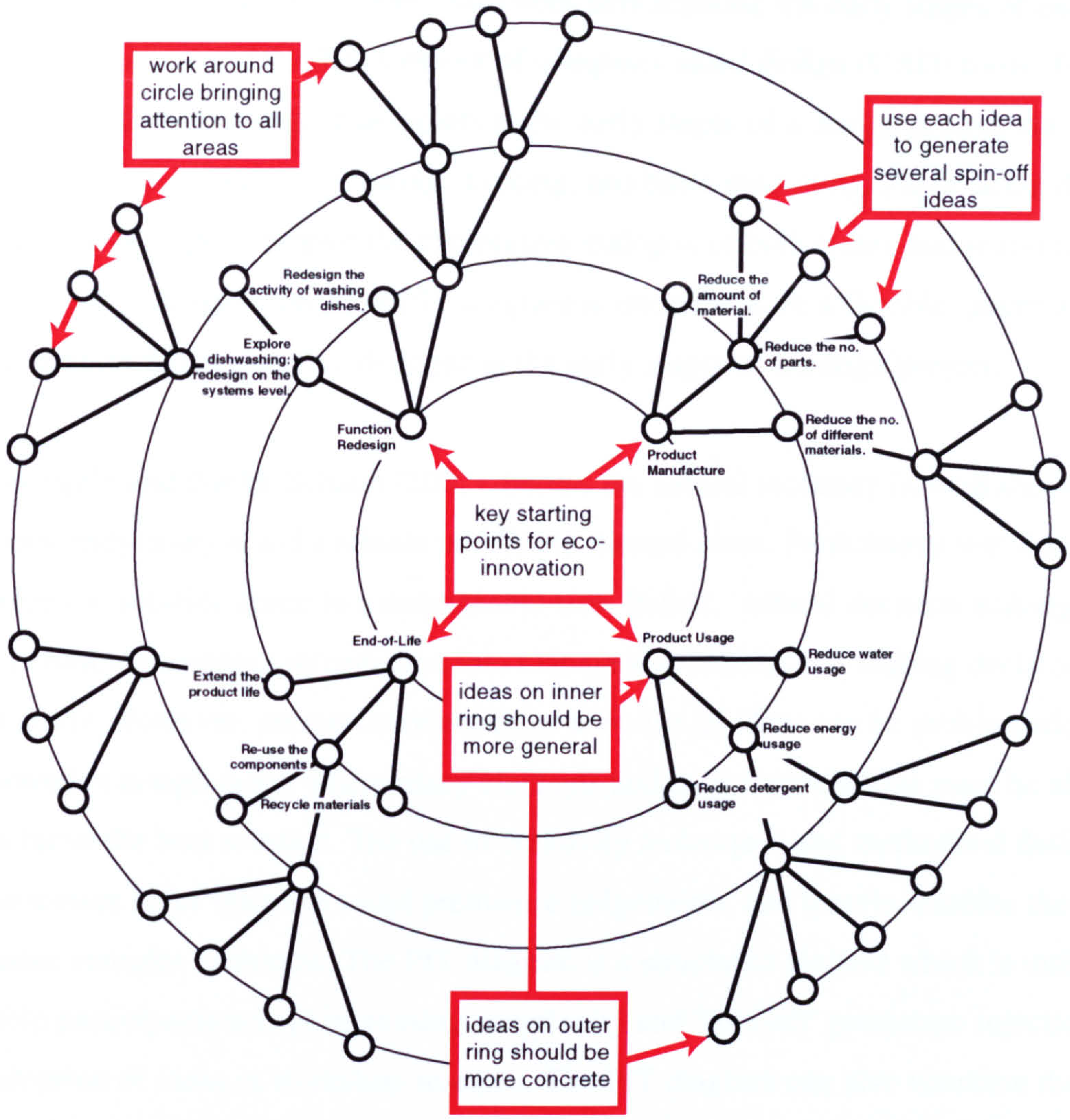


Figure 4.3: schematic of the PIT diagram with pointers showing intended use

The PIT diagram is still different from any existing idea-recording or 'mapping' technique because the ideas are simultaneously clustered according to some key-starting points for eco-innovation and are also placed within a hierarchical ideas structure.

4.4 Aspects of the PIT diagram to be tested

This section summarises diverse research studies on design at the early stages of the design process. Ideas capture, stimuli for idea-generation sessions and participants' collaboration are issues of particular relevance to the proposed PIT diagram experiment.

4.4.1 Improve ideas capture

Stappers and Hennessey (1999) have been investigating the early stages of design practice, to inform the development of computer aided design (CAD) tools. They found that the main activities of designers at the early stages of a design project are 'paper aided', such as sketching, collage making, and basic modelling. Paper-aided design is flexible enough to support the explorative dialogue of both teams *and* individuals at the conceptual design stage. The PIT diagram is intended to be a flexible 'paper aided' tool to support the explorative dialogue at the early stages of a design project.

Stempfle and Badke-Schaub (2002) discuss the natural tendency in workshops to constantly analyse and evaluate in order to discard ideas. Participants will do this to keep the solution space to a manageable size. In fact, 'natural decision making' consists of reducing complex information into manageable chunks and making decisions rather quickly. However, premature rejection or adoption of ideas can be problematic in more complex design tasks, where many elements and their interrelations must be identified to achieve the best solution. The use of creativity techniques and methodical design processes helps teams to avoid premature judgements, and thereby enables them to solve more complex problems. The PIT diagram is a structured method which is intended to help participants accept increasing complexity and 'hold-off' premature rejection or adoption of ideas in workshop sessions. The PIT diagram can also visualise the interrelations in the problem or solution space.

Hanks (1983) highlights the importance of all participants being able to see the recorded ideas simultaneously during the session. He states that new ideas will be expressed as a result of being able to see the interrelations between the ideas already captured. The Mind Mapping technique (described in section 3.3) is an existing tool that can be used to structure the outcomes from creative sessions and highlight the relationships between the ideas. Mind-mapping is acknowledged as a crucial influence on the design of the PIT diagram.

Sonnenwald (1996) has done extensive research on exploration and collaboration in design practice. By observing communication behaviours amongst participants in design practice, she discovered the different 'boundary spanning roles' that participants take on. These boundary-spanning roles are often crucial to a project's success. She recommends that new design methods should support those communication roles and augment the boundary-spanning activity in general. The PIT diagram attempts to fulfil these criteria as it is intended to support knowledge exploration and integration between participants during the project.

The PIT diagram is intended to improve workshop sessions by: supporting the explorative dialogue between participants; helping participants to accept increasing complexity and 'hold-off' premature rejection or adoption of ideas; visualising the interrelations in the problem or solution space. Providing the PIT diagram would improve idea capture by improving the way ideas are recorded in workshops. It was therefore hypothesized that the use of PIT in a workshop would produce more recorded ideas output.

4.4.2 Greater span of environmentally relevant ideas

Workshops in environmental design often have an educational element; a workshop will start with an introduction to the basic principles of environmental design. Frequently, these principles will then be used as stimuli for the idea-generation sessions.

Design research has looked at how stimuli - the information provided at the beginning of the design project - affect the outcomes from workshops. Snoek and Hekkert (1998), for example, found that providing 'context' as a stimulus did broaden the 'solution space' and increase the range of original and appropriate solutions generated. Pasman (2002) has also looked at the effects of providing information at the beginning of the design project. He conducted a controlled design experiment on the effects of providing designers with differently organised databases of precedent designs. From his findings he developed a tool (ProductWorld) for early stages of the design process. His tool should facilitate idea generation by encouraging the designer to engage with precedent designs as stimuli.

In this chapter, the key starting points for eco-innovation provided on the inside ring of the PIT diagram are tested as stimuli. Those key-starting points should provide a greater span of environmentally relevant ideas by stimulating ideas to radiate across the whole surface of the diagram. It was therefore hypothesized that the use of PIT in a workshop would produce more environmentally relevant ideas.

4.4.3 Improve collaboration between participants

The PIT diagram aims to overcome some of the communication problems between participants at the early stages of the eco-innovation process. A number of researchers have taken a closer look at communication problems in design practice. The findings summarised below are relevant to the proposed PIT diagram experiment.

Eckert, Cross and Johnson (2000) describe communication problems in the textile design industry. The main cause of the communication problems they describe is similar to that in environmental design workshops; the participants' disparity in background knowledge and expertise. They propose a computer aided support tool for more accurate and reliable communication between textile designers and technicians at early stages of the design process, based on their extensive research of the knitwear industry.

Sonnenwald (1996) conducted research in *different* design fields to create a *generic* model to facilitate collaboration in the design process. The main communication problems identified are at early stages of the design process when the participants are trying to determine the design requirements. The clarification of ideas and understanding of each other's expertise takes up a lot of time in the process.

Valkenburg (2000) bases her recommendations for improving team designing on reflective practice theory, which advocates participants' awareness of 'frames'. She states that in multi-disciplinary design projects it is even more important to view the frames from different angles (perhaps as hierarchies: frames and sub-frames), so that specialists and experts can contribute their knowledge to a project in a way in which supports the entire design.

The PIT diagram intends to promote collaboration in workshops by providing a fast, accurate and reliable communication tool. Presenting each participant's contributions in relation to the 'bigger picture' should help overcome problems of idea ownership or expertise clash. It was therefore hypothesized that the use of the PIT diagram would help facilitate such creative sessions.

4.5 Methods

In summary, it was hypothesized that the use of the PIT diagram in a creative session would produce more ideas (H1), more environmentally relevant ideas (H2) and would help facilitate such a creative session (H3). These three are treated as separate research questions for the purposes of data analysis and interpretation in the rest of this chapter.

4.5.1 Participants

Twenty participants with a mean age of 21 years were unpaid volunteers recruited from the final years of the following degree courses: Industrial Design (BSc.), Industrial Design Engineering (BSc.), Product Design (BSc.), and Industrial Design and Technology (BA.). These courses all have several core modules in common and in the final year the selected options determine the design specialisation for each of the students.

4.5.2 Experiment Design

Independent variables

The aim of this study was to test aspects of the PIT diagram, for which purpose the PIT diagram was broken down into the two main elements: the radial recording method and the key starting points for eco-innovation. These two between-subject factors were manipulated: (1) the recording method (radial recording method and no method) and (2) the key starting points (key starting points for eco-innovation and no key starting points). Table 4.2 shows how these two factors were crossed, yielding the four experimental conditions.

	no Radial recording method	Radial recording method
no key starting points for Eco-innovation	noE,noR	noE,R
key starting points for Eco-innovation	E,noR	E,R

Table 4.2:conditions allocated to the four groups

Dependent variables

To test the three parts of the hypothesis the following dependant variables were selected for each part.

Use of the PIT produces more ideas (H1).

Initial ideas (A): The number of ideas generated in the first 15 minutes of the experiment, as recorded on the Post-it notes. Expanded ideas (B): The number of ideas generated in the last 15 minutes of the experiment, as recorded in felt-tip pens on the large recording sheet directly.

Use of the PIT will produce more environmentally relevant ideas (H2).

Environmentally relevant ideas: The proportion of the total ideas generated (A)+(B) which were judged by two environmental design experts to be environmentally relevant with, or without, possible rebound effects.

Use of the PIT will facilitate the sessions and make them more constructive (H3).

From video recordings of all the groups, general observations were made on key actions and approaches during the sessions. From the same recordings the last activity of the session (expanding the ideas for 15 minutes) was examined. Four different types of interactions were identified as the categories for content analysis. The number of constructive, analytical, destructive interactions and queries in the session were counted.

Explanation of terms

Radial recording method: a method for recording ideas on a surface that links ideas and simultaneously places them in a hierarchical structure.

Key starting points for Eco-innovation: the key starting points (or workshop prompts) that were distilled from LiDS-wheel and eco-compass. These key starting points were provided on both a generic level and on a more concrete level, as the headings and sub headings show in figure 4.4 below.

Product Manufacture:

Reducing the amount of material in the product.

Reducing the number of parts in the product.

Reducing the number of different materials in the product.

Product Usage:

Reduce water usage

Reduce energy usage

Reduce detergent usage

End-of-Life:

Extend the product life, design for longer life.

Re-use the components, design for upgradability.

Recycle materials, design for ease of separation.

Function Redesign:

Redesigning the activity of washing dishes.

Redesigning the 'dishwashing' system.

Figure 4.4: key starting points for eco-innovation given as workshop prompts

Environmentally relevant ideas: ideas that show potential to reduce the environmental impact of the product or system throughout its life cycle; from materials extraction, through production processes, packaging and transport, product use, to end-of-life disposal.

Environmental impact: detrimental effects related to the use of materials and energy and release of substances into the environment.

Rebound effect: where a (potential) environmental improvement in one part of the product life cycle has a detrimental effect in another part of the product life cycle.

Constructive interactions: all interactions that lead to new ideas output or build on existing ideas leading to new ideas.

Analytical interactions: all interactions that were constructive but did not lead directly to new ideas output, these included activities such as information summaries.

Destructive interactions: all interactions that slowed down the flow of new ideas output, these included activities where the participants failed to reach consensus or disagreed.

Queries: all interactions where the participants queried the methods, task or instructions, this also included all time keeping and hurrying along.

4.5.3 Procedure

Recruitment

The twenty final year students taking part in this experiment were recruited by personal invitation one week before the workshop was held.

Warm up session and grouping

The participants were divided randomly into four groups. To check the uniformity of design *skills* and design *interests* between each of the groups, the following two analyses were undertaken.

For the first analysis, a profile of the participants' different final year options was undertaken. These options were grouped as humanistic options and technological options. Humanistic options were context, graphics and design-related studies. Technological options were all the science or technology options. The groups' profiles of design *skills* were made up by the total number of technological and humanistic final year options chosen by the members of each group.

The second analysis doubled up as the warm-up exercise for the session. Each participant was given 10 minutes to select two pictures from a large bank of different magazines that would depict their design interests. The participants were subsequently divided into the four groups and asked to paste together their pictures on a board. The pictures on these boards were counted and grouped in the following categories: Nature (nature or natural products), Society (social comment or human activity), Architecture (atmospheric interior or social comment) and Technology (cars, high-tech products or highly styled products). The boards now provide a profile of each of the groups' design *interests*. An example of such a board is shown in figure 4.5.

Figure 4.5: Example picture board from warm-up exercise

Table 4.3 summarises the outcomes from these two analyses and highlights the number of participants in each group with Environmentally Sensitive Design as a final year option. The groups were considered adequately homogeneous for this experiment.

	Profile of group design skills			**Profile of group design interests**			
	Number of selected final year options:			Number of images on board depicting:			
	Humanistic options	Technological options	ESD* option	Nature	Society	Architecture	Technology
noE,noR	9	6	2	1	1	5	3
E,noR	9	6	4	0	2	2	7
noE,R	7	8	4	1	4	1	7
E,R	9	6	4	0	2	3	5
	*Environmentally Sensitive Design						

Table 4.3: Summary of design skills and interests

Communal briefing

After the warm-up exercise the groups were briefed communally on the task, the ideas outputs expected, the timing of the different activities within the session, the ideas recording techniques expected at each stage, the operation of the video cameras and timekeeping required.

The task was to generate as many and diverse ideas for improving domestic dishwashing as possible. It was emphasised that the workshop was about recording the way the ideas were generated. The participants were asked to generate as many and diverse ideas as possible and not to criticise ideas or eliminate any ideas. The participants were introduced to some general facts about dishwashing and the dishwasher. Throughout the session they were free to generate ideas on the product (the dishwasher) or the activity level (dishwashing). Each group had a copy of these general facts in their separate session rooms.

The participants were asked to record their ideas throughout the sessions by writing each idea as a single phrase statement. They were asked to avoid compound ideas statements (multiple ideas presented as one idea), by splitting such ideas into several single phrase statements. If ideas were sketched, they were asked to translate those drawings into single phrase statements. Each group had a copy of these idea-recording guidelines in their separate session rooms.

The participants were briefed on the basic session programme for the four 15 minute activities. The activities and the idea-recording techniques expected at each stage were described as follows:

Self-briefing, 15 minutes.

The participants were told that each group would have slightly different instructions to follow for the session. They would be provided with two overheads and one page of accompanying text. One participant would need to volunteer to project these overheads and read the text out.

Individual brainstorm initial ideas, 15 minutes.

The participants were told that the next activity was to individually brainstorm initial ideas. They were asked not to discuss ideas with each other but to record all idea statements on separate post-it notes.

Group discussion sorting ideas, 15 minutes.

The participants were asked to bring together all the post-it notes, create categories to group all the ideas and subsequently place their grouped post-it notes on the large sheet of paper. They were then asked to identify the most interesting areas on the large sheet to explore further in the next part of the session.

Group brainstorm expanding ideas, 15 minutes

The participants were asked to work together to generate ideas that would expand the interesting areas identified. One participant would use felt-tip pen to record all these ideas directly onto the large sheet of paper.

Finally, the participants were briefed on the operation of the video camera and told to start the recording as soon as they entered their separate session rooms. They were asked to appoint a timekeeper to ensure that the basic program schedule was maintained and any deviation from the schedule would be recorded.

Group self-briefing and conduct of the activity

In their session rooms the groups received two of four different instructional overheads and an accompanying text to read. These described the methods that each group was expected to employ. Table 4.4 shows which of the four overheads each group received in accordance with the four different conditions.

	no Radial recording method	Radial recording method
no key starting points for Eco-innovation	**noE,noR** 'classical brainstorming' 'placebo'	**noE,R** 'radial recording' 'placebo'
key starting points for Eco-innovation	**E,noR** 'classical brainstorming' 'Eco-starting points'	**E,R** 'radial recording' 'Eco-starting points'

Table 4.4: Overheads provided for self-briefing

'Classical brainstorming'

The rules of 'classical brainstorming' (Osborne, 1963) were taken as the 'no recording method' because all groups were expected to abide by these basic rules during the session. The basic rules are to suspend all criticism, encourage freewheeling and desire a large quantity of ideas.

'Radial recording'

For the groups using the radial recording method the first part of their session was identical to the other groups. However, in the second part of the session they were expected to mark their ideas groups on the inner ring of their large sheet of paper which had been pre-marked with four rings. Ideas closest to the inner ring should be more general and ideas on outer ring should be more concrete. In the final part of the session they were asked to expand the interesting areas on the sheet by using each idea to generate several spin-off ideas and by working around the circle to bring their attention to all areas on the sheet.

'Eco-starting points'

The groups that were provided with the eco-starting points were asked to consider those starting points as design directions whilst generating ideas, but were asked not to rule out other idea directions. This was done to ensure that all groups would feel the same degree of freedom to produce ideas; to ensure that the total ideas count (A) would not be affected negatively by providing these the key starting points. The key starting points provided are listed in figure 4.4.

'Placebo'

The placebo was an activity designed to occupy the groups that were not briefed with eco-starting points. This activity would take roughly the same amount of time, but would not influence the group's behaviour. These groups were simply put in 'un-prepared' rooms and asked to arrange their furniture and hang their recording sheet on a convenient wall.

De-briefing

For the de-briefing session the groups came together with their ideas output. This enabled each group to compare their efforts if they wished. Each group was asked how they felt their sessions had gone and this informal feedback was recorded.

4.5.4 Equipment

All groups had the following equipment: post-it notes, pens, felt-tip pens, a large sheet of paper (1.5 x 1.5 m), the dishwashing fact sheet, the task sheet, a video camera, a stop watch, an overhead projector, two overhead slides and accompanying text. (noE,R) and (E,R) had four pre-marked rings on their large sheet of paper. (E,noR) and (E,R) also had eco-starting points on pieces of card and blue tack to attach these to the large sheet of paper.

4.5.5 Data analysis

Use of the PIT produces more ideas (H1)
Initial ideas (A) were counted from the number of post-it notes produced. Expanded ideas (B) were counted from ideas that were written in felt-tip pen on the large sheet. Many of these ideas (B) were restatements of initial ideas and only few were genuinely new ideas. Therefore, the ideas (B) were separated into two groups: restatements of initial ideas (B1) and genuinely new ideas (B2).

Use of the PIT will produce more environmentally relevant ideas (H2)
Two environmental design experts categorised all the ideas statements (A)+(B), they had to judge the statements to be either environmentally relevant ideas (with or without possible rebound effects) or ideas which were environmentally irrelevant or detrimental. An inter-observer reliability check was performed which revealed a moderate, and statistically significant, correlation between the two environmental design experts ($rho=0.47$, $p<0.001$). A cautious approach was taken with these data and only where both environmental design experts agreed that the ideas were environmentally relevant with or without possible rebound effects, were they counted (C). The rest of the ideas (D) were discounted (D)= ((A)+(B))-(C). The chi- square test was undertaken to test the difference between the conditions (noE,noR), (E,noR), (noE,R), (E,R).

Use of the PIT will facilitate the sessions make them more constructive (H3)
The video recordings of the last activity of the session were analysed by identifying four different types of interactions, and counting their frequency. Previous studies of team interactions have used this sort of analysis (Pritchard & Stanton, 1999). The four types

of interactions identified were the number of constructive (E), analytical (F), or destructive interactions (G) and the number of queries in the session (H). To add to the quantitative data in this study the complete video recordings were watched and general observations were made on the actions and approaches taken by the groups.

4.6 Results

4.6.1 Quantitative Data

Use of the PIT produces more ideas (H1)

Table 4.5 presents the initial, expanded and total idea counts from this study and reports on the quality of the expanded ideas.

		A: Initial idea	B: Ideas expanded	total ideas count:	B1: Re-statements	B2: Genuinely new
noE,noR	N=	132	21	153	21	0
	row %	86.30%	13.70%	100%	13.70%	0%
E,noR	N=	75	20	95	16	4
	row %	79.00%	21.00%	100%	16.80%	4.20%
noE,R	N=	94	18	112	12	6
	row %	83.90%	16.10%	100%	10.70%	5.40%
E,R	N=	86	5	91	2	3
	row %	94.50%	5.50%	100%	2.20%	3.30%

Table 4.5: Initial and expanded idea counts and row percentages

The PIT diagram is designed particularly to assist in the expanding of ideas part of the session; (noE,R) and (E,R) were therefore expected to produce more expanded ideas (B). However, table 4.4 shows that (noE,noR) and (E,noR) produced most expanded ideas.

When examining the quality of the expanded ideas, it was found that many of these ideas (B) were restatements of initial ideas and only few were genuinely new ideas. The ideas (B) were classified as either: restatements of initial ideas (B1) or genuinely new ideas (B2).

Table 4.5 shows that (E,noR), (noE,R) and (E,R) produced some genuinely new ideas but (noE,noR) produced no genuinely new ideas (B2). This might indicate that all groups with some methods performed better in this aspect than the 'no method' group.

(E,noR) and (noE,R) also had a relatively high proportion of their output in the expanding of ideas part of the session (B). The row percentages show that (E,noR) and (noE,R) were the most productive groups in this part of the session, scoring 21% and 16.10% respectively.

Use of the PIT will produce more environmentally relevant ideas (H2)

Table 4.6 presents the results from the two environmental design experts: the number of environmentally relevant and discounted ideas, as well as the row percentages and expected values.

		C: Env. relevant ideas	D: Discounted ideas	total ideas count:
noE,noR	N=	113	40	153
	row %	74.00%	26.00%	
	expected values	*96.35*	*56.65*	
E,noR	N=	59	36	95
	row %	62.00%	38.00%	
	expected values	*59.82*	*35.18*	
noE,R	N=	55	57	112
	row %	49.00%	51.00%	
	expected values	*70.53*	*41.47*	
E,R	N=	57	34	91
	row %	63.00%	37.00%	
	expected values	*57.3*	*33.69*	
		284	167	451

Table 4.6: environmentally relevant and discounted ideas, row percentages and expected values

The key starting points for eco-innovation were intended to help the groups produce more environmentally relevant ideas throughout the session, (E,noR) and (E,R) were therefore expected to produce more environmentally relevant ideas (C). However, table

4.6 shows that (noE,noR) produced the most environmentally relevant ideas. Which prompted a closer look at the *proportion* of the ideas which were judged to be environmentally relevant.

The chi square (χ^2=19.891, $p<0.001$) test showed that the observed frequencies differed significantly from the expected values. This meant that the generation of environmentally relevant ideas (C) was affected by the independent variables, allowing conclusions to be drawn about the four different conditions.

Table 4.6 shows that (E,noR) and (E,R) produced only an average proportion of ideas that were judged environmentally relevant, 62% and 63% respectively. (noE,noR) had the highest proportion of ideas that were judged environmentally relevant (74%).

Use of the PIT will facilitate the sessions and make them more constructive (H3)
Table 4.7 shows the results from counting the four different types of interactions in the last activity of the session and their row percentages.

		E: constructive interactions	F: analytical interactions	G: destructive interactions	H: queries	total interaction count
NoE,noR	N=	48	54	11	15	128
	row %	37.50%	42.20%	8.60%	11.70%	
E,noR	N=	64	28	1	7	100
	row %	64.00%	28.00%	1.00%	7.00%	
NoE,R	N=	74	20	1	9	104
	row %	71.20%	19.20%	1.00%	8.60%	
E,R	N=	47	22	2	20	91
	row %	51.60%	24.20%	2.20%	22.00%	

Table 4.7: interactions counted and row percentages

It was hypothesized that The PIT diagram would help facilitate creative sessions by providing structured visual output which communicates progress to all participants in the creative session, (noE,R) and (E,R) were therefore expected to work more constructively. A higher number of constructive (E) and analytical (F) interactions was expected in these groups. However, table 4.7 shows that (E,noR) and (noE,R) were most constructive and (noE,noR) was most analytical.

Table 4.7 shows that (E,noR) and (noE,R) had the highest proportion of constructive (E) and analytical (F) interactions, 92% and 90.4% respectively. This is supported by the qualitative data summarised in table 4.8.

All groups that had some methods - (E,noR), (noE,R) and (E,R) - had very low proportions of destructive interactions (G) 1%, 1% and 2,2% respectively. By comparison, the (noE, noR) group had a high proportion of destructive interactions (8.6%).

The group with both methods (E,R) had a particularly high proportion of method, task or instruction queries (22%).

4.6.2 Qualitative Data

The qualitative data in this study has been invaluable for providing insights into the methods used in this experiment as well as providing explanations for the unexpected results in the quantitative data.

Table 4.8 summarises the notes made whilst watching the complete set of video recordings. Some of the key observations are underlined. The four columns represent the four activities of the basic session program described in section 4.5.3. Each activity was intended to take 15 minutes. Table 4.8 also reports the actual times taken for each activity.

	self-briefing	individual brainstorm initial ideas	group discussion sorting ideas	group brainstorm expanding ideas
(noE,noR)	**9 min. 45 s.**	**15 min. 35 s.**	**30 min. 15 s.**	**17 min. 27 s.**
	- individually read the 2 original briefing sheets - missed the 'brainstorm' overhead, but did read out text	- ideas generation slowed down seriously after 10 min.	- after 3 min. groupings are created without much discussion or conflict - after 15 min. ideas had been grouped, confrontational discussion on doubles and meanings - after 20 min. filtering and failing to reach consensus did not identify 'interesting' areas to expand, but left 'sensible' ones on the large sheet	- more constructive interactions and consensus - 2 members recording consensus ideas from existing ideas - 2 other members expanding ideas in discussions which were not recorded
(E,noR)	**12 min. 33 s.**	**14 min. 01 s.**	**21 min. 40 s.**	**13 min. 40 s.**
	- first few minutes some general unrelated chat - individually read the 2 original briefing sheets - tried to fill up time, read out the dishwashing briefing sheet to the group	- after 5'30" completely stopped generating ideas, chatted about kitchen-related objects and anecdotes for 6'30" - last 2 minutes disciplined themselves to generate 2 more ideas each, some discussion on whether 'stupid' ideas counted	- grouped ideas for 8'30" by calling out: 'has any one got?' very constructive - after 10 min. identified most interesting areas - had not named their groups but agreed on: 'styling concepts' and 'washing concepts' - after 17'30" started fitting Eco-starting point cards to their groups	- interesting areas chosen 'function redesign' and 'redesign at the system's level' - recorder hesitant to take down new ideas, members confirmed: 'yes, we can expand' - several ideas successfully expanded but only sensible ones taken down about 3 other new ideas missed
(noE,R)	**11 min. 05 s.**	**15 min. 08 s.**	**30 min. 32 s.**	**14 min. 18 s.**
	- read out information on the overheads, without text - read out the 2 original briefing sheets - read out the text to go with the overheads - confirmed scope of ideas 'we don't have to be environmental about this'	- ideas generation slowed down seriously after 10 min. - persisted with individual ideas generation for another 5 min.	- duplicate post-its were removed by this group: lost at least 6-10 initial ideas - groups were easily determined, ideas on boards first, individuals called out for consensus - after 15'30" started using sheet, agreed on hierarchy, slow tentative placing of ideas - increased participation towards end.	- realised there was another activity - explained to the camera: the hierarchy, overlapping boundaries, inside vague generic, outside implement. - great ideas expansion due to statements as: 'so, could we have...?' and 'just keep going round' - 1 expanded idea missed on the sheet
(E,R)	**10 min. 56 s.**	**14 min. 49 s.**	**29 min. 04 s.**	**19 min. 11 s.**
	- read out text with overheads, spent some time individually ingesting the information, little discussion - read out the 2 original briefing sheets	- ideas generation slowed down seriously after 8 min. - persisted with individual ideas generation for another 7 min.	- laid out post it notes, grouping very slow and low key, no debates - force fitted their groups with the headings on the cards after 20 min. placed the cards and groups on the sheet, copied the overhead layout - one member used the rings but did not explain the understanding to the others.	- very low motivation, very little chat about the ideas, only about the method highlighted the interesting ideas and realised that they still needed to expand them - in the last 2/3 minutes they took down some expanded ideas, 2 not recorded - at least one idea not recorded

Table 4.8: Actual times taken and summary of observations from watching the video recordings.

The most important observations from watching the video recordings were that all groups:

- had excess time in the self-briefing and individual brainstorm parts of the session;
- were short of time and struggled in the 'group discussion sorting ideas' part of the session;
- missed recording some ideas in the last part of the session, this meant that the expanded ideas (B)(B1)(B2) counts were affected.

Specific group-related observations were as follows:
(noE,noR) had most arguments and problems reaching consensus. However, they were the most dynamic, unconstrained group and produced the largest quantity of ideas.
(E,noR) worked very constructively as a team, although they missed a lot of their output on the large sheet. This may have been due to their hesitant recorder.
(noE,R) were disciplined and worked very efficiently throughout the session. They were particularly successful at creating genuinely new ideas during the expanding ideas part of the session. This may have been due to the good facilitation by their recorder.
(E,R) was the least dynamic group, they interacted least and did not debate or communicate much amongst themselves. They were the only group that seemed to find the session a chore.

4.7 Discussion

The aims of the experiment were to: establish which attributes of the tool were most beneficial in the workshop session; to make suggestions for the further development of the PIT diagram; and provide insights into better ways of testing such a recording tool. The following section discusses the main findings and contributions made by this study.

4.7.1 Evaluation of the Experimental Hypotheses

Use of the PIT produces more ideas (H1)

Unexpected results for this part of the hypothesis were the particularly high ideas score (A)+(B) of the 'no method' group (noE,noR) and the low total ideas score of (E,R) who had both methods. (noE,noR) may have felt least constrained due to the absence of any special methods and (E,R) may have felt over-constrained by method instructions. The groups with some methods (E,noR) and (noE,R) were most productive in the expanding of ideas part of the session. Their tools may have provided an appropriate level of structuring for this session. This means that providing too many tools or methods may inhibit the quantity of ideas produced.

Use of the PIT will produce more environmentally relevant ideas (H2)
All groups produced notably high proportions of environmentally relevant ideas. A high number of participants were trained in Environmentally Sensitive Design (ESD) (see table 4.3) and had, by coincidence, completed their final exam in ESD on the morning of the experiment. Group (noE,noR) were not constrained by any specific methods and may therefore have used more of their thoughts from the morning, this may explain their high proportion of environmentally relevant ideas. Providing the key starting points on cards may therefore not have provided any extra advantage to (E,noR) and (E,R). This means that providing environmental prompts offers no advantage for producing environmentally relevant ideas, when the participants have already been trained in Environmentally Sensitive Design.

Use of the PIT will facilitate the sessions and make them more constructive (H3)
(E,R) scored fairly low in the proportion of constructive and analytical interactions (E)+(F) and fairly high in the proportion of method, task or instruction queries (H). This suggests that (E,R) may have felt over-constrained by method instructions. Complex methods seem to initiate more queries - this may be an artefact of the participants' inexperience with the method, and may be reduced over time and with practice. This experiment did show that all groups with some methods (E,noR), (noE,R) and (E,R) had very low proportions of destructive interactions (G). This means that providing a tool or method of some sort does reduce the number of destructive interactions in the groups.

Increasing the sample size would help determine whether the level of constructive communication was associated with the group dynamics or the four manipulated conditions. The qualitative data helped provide explanations for the quantitative data. The qualitative data highlighted a number of factors that may have influenced the use of the methods. The groups all had different interpretations of the instructions and different levels of discipline. There were too many instructions to be remembered by the participants throughout the session. The groups tended to deviate from the basic session program and violate some of the session rules unless there was at least one participant referring back to the overheads or the task sheet. Discipline in time keeping also varied between the groups. Some groups cut themselves short whilst still expanding ideas, whilst others worked on until the ideas 'ran dry'.

Perhaps the largest factor influencing the expanded ideas count (B) was each groups appointed 'recorder': how effective were they at taking down the groups' ideas; how enthusiastically did they facilitate in the last part of the session; and how well did they understand the methods they were using?

4.7.2 Benefits of the PIT diagram

The PIT diagram did produce a relatively high number of genuinely new ideas in the last part of the session. The period after the flow of initial ideas has 'run dry' is a difficult time in workshops. The PIT diagram seems to be a useful tool at this stage. The groups with the PIT diagram also produced a high proportion of environmentally relevant ideas. The diagram's visual structure may have made the groups more aware of which ideas would lead to environmental improvements in the products, highlighting which ideas would need to be pursued further for eco-innovation.

Those groups with methods in their sessions had a particularly low number of destructive interactions. Using structured tools, such as the PIT diagram, in creative sessions does improve constructive communication between the participants.

4.7.3 Problems encountered testing the PIT diagram

The complexity of combining the radial recording method and the environmental starting points may explain some of the difficulties encountered by the (E,R) group. This could be improved by simplifying the tool or its instructions further. Alternatively, the PIT diagram might be used more successfully if one member of the team was trained in the use of the tool, thereby free-ing up other members of the team to simply generate ideas.

When used in creative sessions, the PIT diagram with key-starting points for eco-innovation is designed to provide a great *span* of potentially environmentally relevant ideas. Therefore counting the number of ideas was perhaps not the most appropriate data to collect. A dependent variable that says something about the spectrum of ideas would be more useful. Judging the environmental relevance of ideas could also be improved. The environmental relevance criteria need to be developed further to help judge to what *extent* the ideas are environmentally relevant, thereby providing richer data about the performance of the tool.

This experiment used a typical brainstorm sequence of activities: individual brainstorm on post-it notes, grouping ideas, and team generating ideas. This approach may have restricted the use of the PIT diagram. The PIT diagram should allow participants to expand ideas from key-starting points, and create a span of ideas that radiate across the whole surface of the diagram. The excess time in the individual brainstorm part of the session meant that unmanageable numbers of post-it notes were created. The large number of post-it notes made the grouping of ideas very difficult. The rings of the PIT diagram became over-crowded and confused. Figure 4.6 shows an example of the over crowding of post-it notes on the large sheet of paper.

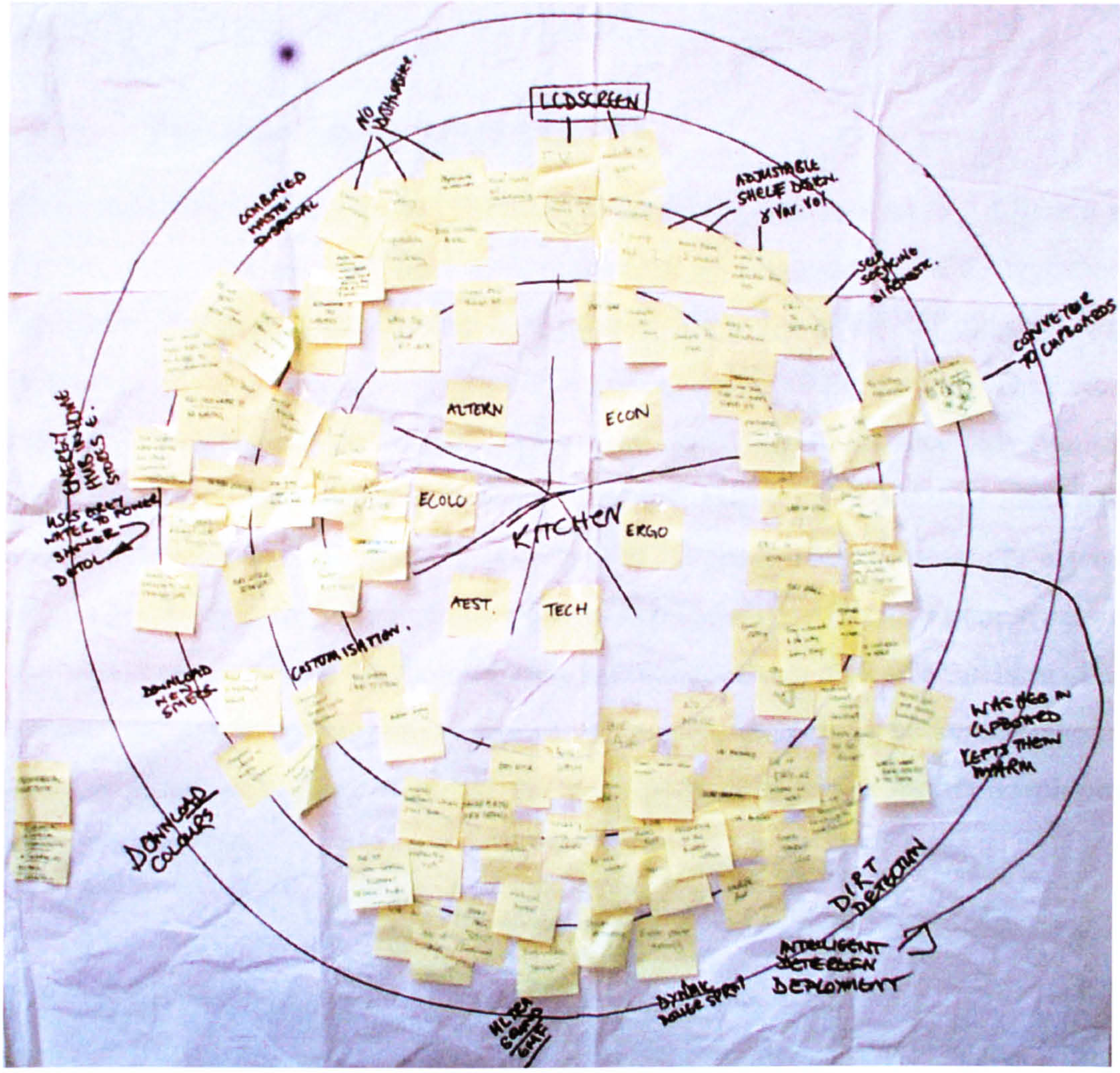


Figure 4.6: Shows the over-crowding of post-it notes on the large sheet of paper (noE, R)

In future experiments the PIT diagram would not be tested using a typical brainstorm sequence of activities. The first activity ‘individual brainstorm ideas’ would be limited or cut out completely. The groups using the PIT diagram would have a large sheet with pre-printed rings and key starting points, and be allowed to record directly onto the sheet, similar to example shown in chapter 3 (section 3.4.2)

The video recordings illuminated a reliability problem with the data recorded on paper by the groups: some post-it notes were ‘lost’; some groups slipped into the habit of filtering or eliminating ideas even though they had been briefed not to; many expanded ideas were not recorded at all; many expanded ideas were not recorded in felt-tip pens thereby confusing the ideas counts (A) and (B). In future experiments the data could be collected by trained observers or recordings could be analysed to provide more reliable data.

4.7.4 Further development of PIT

After conducting this experiment, the same dishwashing task was set to a different group of participants, in a less controlled environment but adopting some of the suggestions from above. All groups were briefed communally on the use of the PIT diagram, with an opportunity to ask questions, ensuring a full understanding of the method. They were only given three minutes for the initial ideas stage and asked to produce only four or five post-it notes each. Each group in this small trial successfully grouped their ideas and placed them in hierarchies on the rings of the PIT diagram. They successfully expanded ideas in a very short time. The quality of ideas that came out of this 20 minute session were very similar to those recorded in this experiment, which took over an hour. This informal study shows the benefit of ensuring that participants fully understand the workings of the method and demonstrates the opportunities for the further development of the PIT diagram.

4.8 Conclusions

This study shows that a tool or structured method will assist idea generation in workshops by improving the constructive communication between the participants. The PIT diagram improves the ability of groups to produce ideas after initial ideas have 'run dry'. However, if the PIT diagram is going to specifically address the communication issues between different participants in the eco-innovation process, then in future the tool must be tested with team members from different disciplines.

This research also identified some potential problems with the introduction of a tool such as the PIT diagram. 'Over-structuring' workshops may lead to the participants feeling like they are working on a chore. Also, unfamiliarity with the new tool may slow down the idea-generation process.

The PIT diagram offers a promising new approach for workshops: enabling groups to work together from the start of the session, removing the need for individual initial brainstorm ideas. The PIT diagram also shows the potential to help generate radical new concepts for eco-innovation in relatively short workshops. However, this research also identified shortcomings in the testing methods used in this study. If this experiment were to be conducted a second time: the participants would be trained in the use of the tool to ensure full understanding, the spectrum of ideas would be assessed; and the criteria for judging environmental relevance would be developed further.

Chapter 5 Structured Innovation methods

Chapters 3 and 4 focused on improving idea-capture at early stages of eco-innovation. The studies reported that it is possible to facilitate the early stages of eco-innovation with the PIT diagram, by capturing a large number of ideas and improving the collaboration between participants. However, as Snoek, Hekkert and Christiaans (1999) point out, the generation of a great quantity of original, radical ideas does not necessarily help participants translate these into appropriate solutions.

To improve eco-innovation, methods are needed that can help transform the enlarged solution space into original *and* appropriate solutions. The rest of this thesis looks at approaches to help provide appropriate solutions that have a greater potential to be taken up in industry. The aim is to encourage ideas for step-change improvements but also to consider how these can be translated into solutions that are more likely to be taken through to implementation.

Mainstream innovation research sees an increasing number of structured innovation methods to help reduce the risks and lead-times associated with the process of transforming novel ideas into marketable products. Most of these methods have not been investigated for their potential to contribute to environmental innovation. This chapter provides a review of structured innovation methods from mainstream practice to inform the improvement of eco-innovation. This chapter also provides the broader context of design and innovation management within which to place the tools and methods proposed.

First, design process theory is revisited to establish a simplified generic model of the design process. Then various theories and models for the management of the design process are reviewed; section 5.2 looks specifically at what factors are required to get ideas through to the implementation stages. Subsequently, section 5.3 explores the management of innovation, and the theories for good practice in innovation are summarised.

The main body of this chapter is the review of popular tools and methods that may help to structure innovation. The 'good practice' criteria from section 5.3 and the simplified generic design process from section 5.1 are used to evaluate the tools reviewed. Some conclusions are drawn about the tools that may be the most interesting for this research.

5.1 The design process

This chapter broadens the theoretical frame within which the research was conducted. There is a large range of written material within the different subject areas of design and innovation, their management and methods. This thesis reports on practice-based research and was lacking an overview of design and innovation theory. In his book on 'demystifying' the design process Lawson (1990) reminds us of the importance of looking at what designers actually do and questioning the usefulness of prescribed design models and methods, and even of design research itself. This thesis acknowledges the importance of bringing together practice and theory in design research.

Although this research focuses on the early stages of the process, the tools and methods proposed must produce original and appropriate solutions with the potential to be taken up in industry. This research uses a simplified generic model of the design process to organise the review of innovation tools. That model of the design process is used to determine whether the methods reviewed (in section 5.4) have 'strong points' spanning across the different stages of the design process. A similar review was previously conducted (Cavallucci, 1999) and proved useful in determining which methods would be suited to the needs of designers tackling innovative projects.

5.1.1 Why add structure to the design activity?

Design has become a team activity with different design expertise and external stakeholder inputs required at different stages. Cooper and Press (1995) describe it as 'an interdisciplinary activity of some complexity'. The design activity needs to be more structured in order to manage the tasks and outputs required from the team members. Standards and policies are necessary to ensure that company objectives are met and quality is consistently achieved.

There is some evidence suggesting that designers use solution-focused rather than problem-focused strategies Lawson (1990). This traditional, solution-focused design relies on an heuristic approach; where designers use previous experience, general guidelines and 'rules-of-thumb' to move the project in 'the right direction'. The designer's emphasis is often on reaching a solution rather than understanding the problem. The increasing complexity of today's design activity - including the development and incorporation of new technologies - means that designers can no longer rely on the heuristic approach (Cross, 1994). Design problems can no longer be comprehensively stated or held in the designers mind simultaneously (Lawson, 1990). Providing structured methods helps designers look into the 'real' problems and balance the solution-focused and problem-focused strategies.

Market forces are shortening the lead-times to production, and the efficiency of all processes - including the design process - must be improved for companies to remain competitive. The large scale of production also means that investment risks are high and that the design process must aim for 'guaranteed' success. The automation of production and the increasing strength of the link between production and design through the improvement of CAD software systems, form other drivers for a more systematic design process.

5.1.2 What is the design process?

The literature makes little differentiation between the 'new product development process' and the 'design process'. Both aim to successfully design, develop, produce and launch products into the market.

Cooper and Press (1995) identify two different ways in which 'design process' is referred to: as the process that a designer goes through, or as the process of managing a product's development. This chapter acknowledges both these views of the design process.

A general definition of the design process given in the Government Design Toolkit developed by the Design Council (2000) is: 'the design process consists of a series of sequential and concurrent actions towards achieving a desired outcome to a project. The design process can vary in structure and complexity depending on the nature of the project but usually consists of five identifiable stages: trigger, brief, development, production and evaluation.'

Definitions of the design process may be quite simple and clear but there are problems associated with researching design processes in practice. The first is that the design process can appear endless. When involved in the design activity it is difficult to recognise the 'correct answer' or a 'finished design'. Designers do not experience a natural end to the design process. Lawson (1990) observed that 'Designers simply stop designing either when they run out of time or when, in their judgement, it is not worth pursuing the matter any further.' The second problem is that there is no single 'correct' design process, and the same designer will even adapt his process to each project he works on. This makes the nature of design research somewhat slippery. However, Thackara (1997) suggests that defining the design process is not too important, as long as there is an understanding of its importance in industry.

In general, the purpose of looking at design processes is to look for a sequence of distinct and identifiable activities which occur in some predictable and identifiably logical order. The specific purpose for this thesis was to establish a simplified generic model of the design process in order to organise the review of innovation tools. However, the design processes reviewed varied considerably and the next section looks at some of the different types or classes of processes.

5.1.3 Models of the design process

This section describes four different ways in which design processes can be classified, with examples of each type. The section draws some conclusions about which models or descriptions of the design process are most relevant to this study.

Descriptive or prescriptive processes

This differentiation between processes is often referred to in the literature. Lawson (1990) for example, noticed when reviewing various models of the design process that many models tended to be theoretical and prescriptive rather than descriptive. Many models seemed to have been derived more from thinking about design than by experimentally observing it. Cross (1994) views this as less problematic and reviews several descriptive and prescriptive models of the design process separately. The descriptive models are based on sequences of observed activities that occur in designing. The prescriptive models exist in order to encourage designers to adopt improved ways of working.

An example of the prescriptive model is that by Archer (1984), which decribes six different activities and features several feedback loops. He did however base his original model on case studies from the field of engineering and further comparisons of processes from different disciplines. An example of a descriptive model is that by French (1985), based on the activities typical in conventional engineering design. His model contains both activities and outputs expected from various stages.

This thesis contributes to practice-based research, and looks at the design activity as it occurs, therefore descriptive models might be most relevant. However, prescriptive models tend to include more interactions with the 'world' outside the designer's realm and therefore provide better models through to the implementation stages. Both types of process are therefore valuable in this study.

Sequential, iterative or concurrent processes

The second way in which processes are differentiated in reviews are as sequential, iterative or concurrent processes. The sequential models describe the design process as a series of sequential steps with expected outcomes at each stage, sometimes including yes/no stage-gates. The iterative models describe the design process as an iterative (or even cyclical) process with several inter-connected stages. In concurrent models the different phases of the process overlap or take place simultaneously.

The sequential models of the design process were some of the first models to describe the process of getting new products to market. These models have been useful for the development and integration of design management and 'mainstreaming' of design practice over the last decades. Examples of such models include: the 'Total Design' model by Pugh (1997); the' Idealised design Process' from the British Standard Guide to Managing product design (BS7000, 1989) and a much-referenced model of the design process by Pahl and Beitz (1995).

All of these models include descriptions of expected 'deliverables' from each stage of the process. The output and review of those deliverables allows the project to pass through the 'stage gate' to the next stage in the sequential process. However, all authors recognise that iterations do occur and that some activities will occur simultaneously. To this end, most sequential models include one or more iterative loops.

Iterative or cyclical models of the design process acknowledge the non-sequential nature of the design activity and development of innovative new products. These models are more likely to have been developed based on observations of design practice.

One of the first examples of such an iterative model is the three-phase design process described by Jones (1992). Design theorists tend to agree that designing is made up of three basic activities: analysis, synthesis and evaluation. Designers will cycle through these activities several times throughout a project, normally with the cycles becoming more detailed and less general in nature. Jones (1992) advocates this very basic model of the design process because it facilitates discussion and development of design theory based on practice. This model has been adopted and referred to by other writers such as Hubel and Lussow (1984) and Lawson (1990).

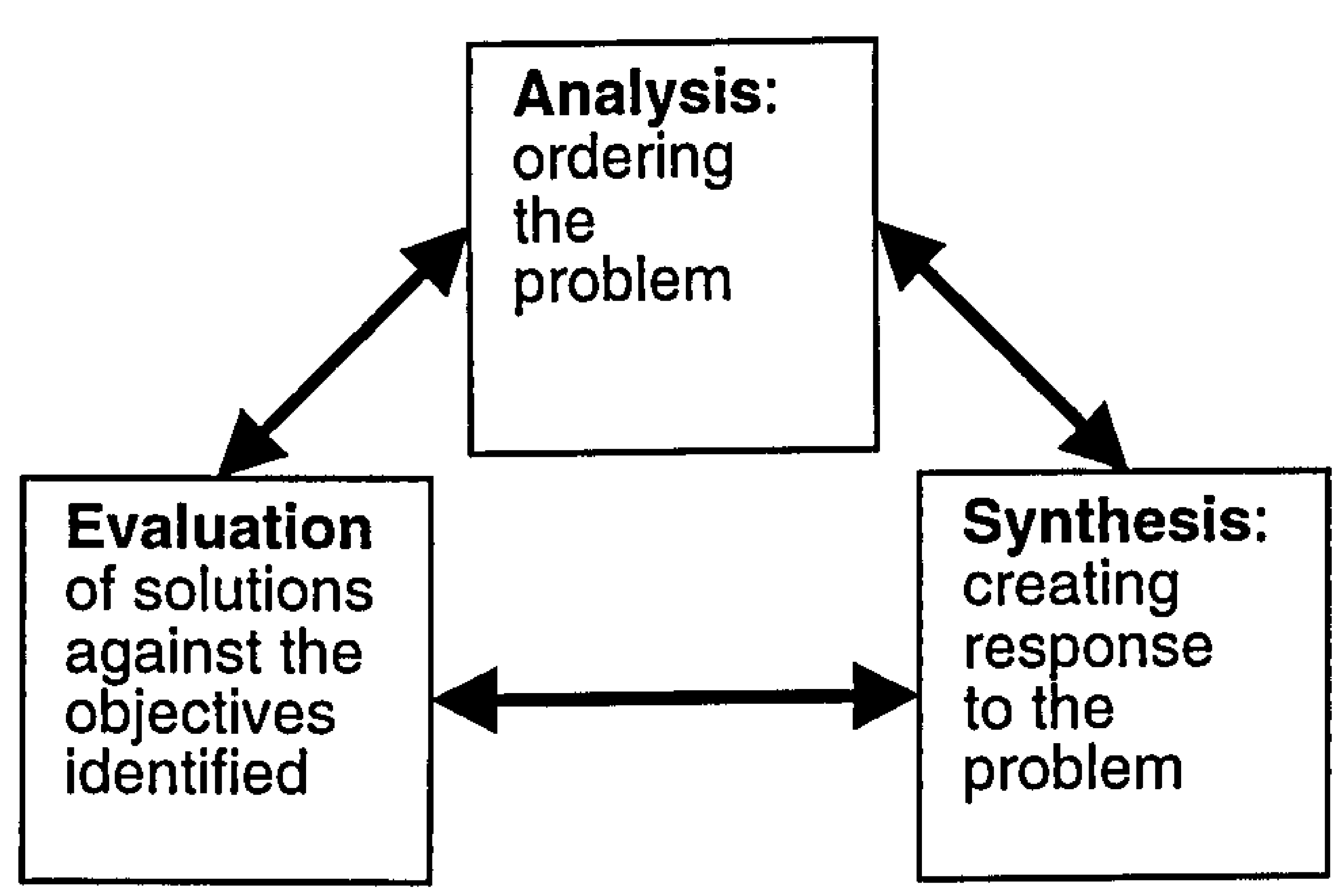


Figure 5.1: Design process after Lawson (1990)

One of the problems with the cyclical model of the design process identified by Cross (1994), is that designers can get trapped in such an iterative loop of decision-making.

Knot (2001) a practising design manager from the aerospace industry, has developed an iterative and evolutionary model of the design process from observations made in his industry. His model shown in figure 5.2 contains arrows that go outside the 'existing knowledge' circle which prevent the cycle becoming a 'trap'. One of the arrows represents new understanding that may affect the original requirements set, the second arrow represents the important decision that is made to 'stop the design process' and move towards implementation.

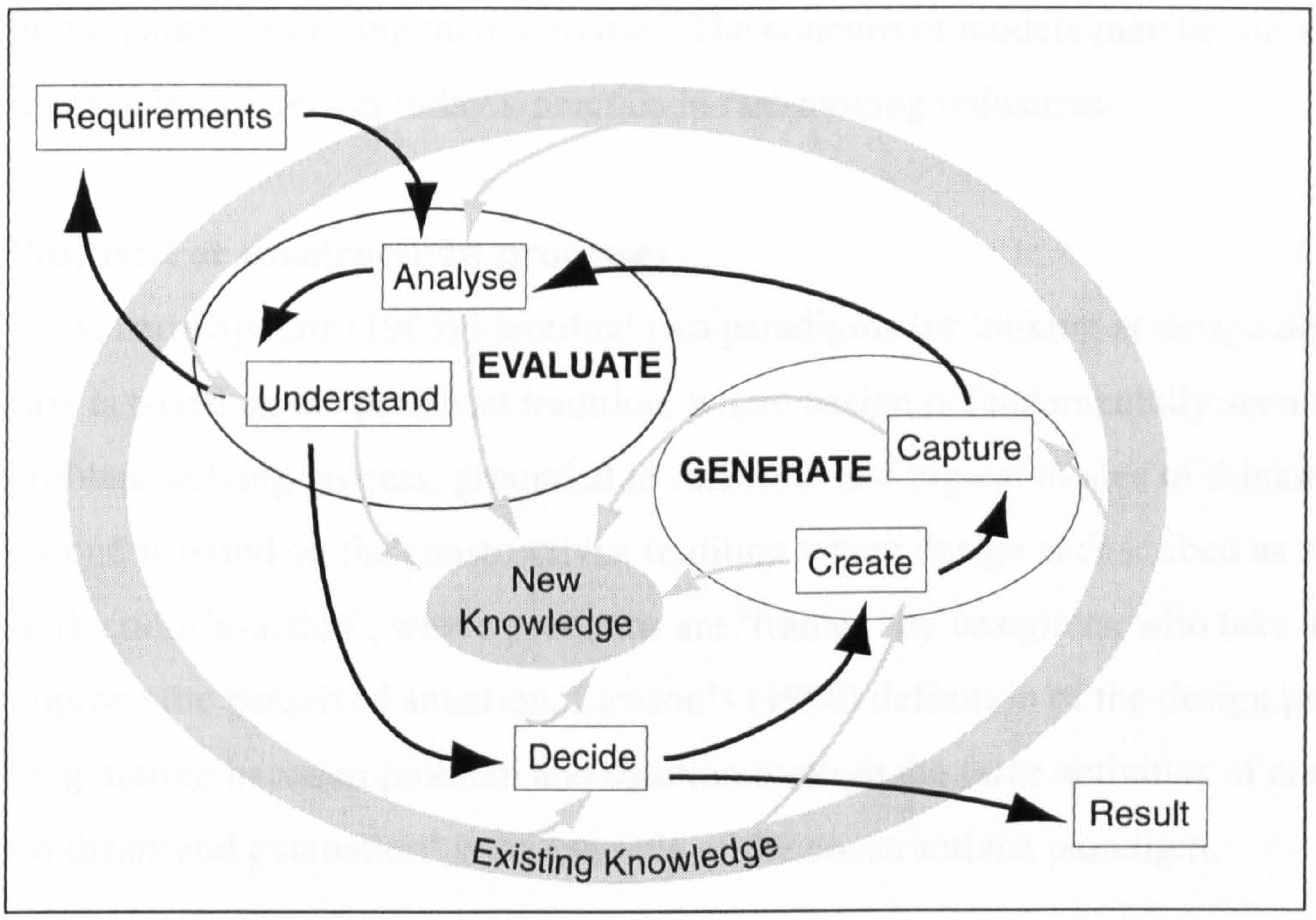


Figure 5.2: Design process after Knot (2001)

Roy et al. (1996) describe a gradual change in design processes from sequential and iterative models to those which can be described as integrated, phase overlapping or concurrent models. This way of working means that the different activities required for new product development take place simultaneously. Individuals and departments involved are integrated and work together as a development team. These concurrent models come forth from a need to make the new product development process more efficient and speed up 'times to market'. This process is more difficult to manage and is only more efficient if it *is* managed well.

The most quoted example of such a concurrent model is the Integrated Product Development model by Andreasen and Hein (1987). In their model, the three disciplines of marketing, engineering design and production development work towards the same goal simultaneously, providing mutually dependent outputs. Their model was developed to counter the departmentalisation in companies caused by increased complexity in the development process.

This section has discussed three different ways of looking at the design process. The iterative models of the process seem to reveal more about the actual behaviours of participants, describing their activities. The concurrent models may be more difficult to manage but do reflect today's practice in fast-moving industries.

Positivist or constructivist processes

Dorst and Dijkhuis (1995) identified two paradigms for looking at design activities. The first is based on the positivist tradition, where design is fundamentally seen as a rational problem-solving process, grounded in scientific and logical modes of thinking. The second is based on the constructivist tradition where design is described as a process of 'reflection-in-action', where problems are 'framed' by designers, who take action to improve the perceived situation. Lawson's (1990) definition of the design process as, 'negotiation between problem and solution through the three activities of analysis, synthesis and evaluation' is an example of the constructivist paradigm.

Both paradigms are investigated in design research and add to the understanding of design practice today. Most practice-based research in the constructivist tradition is relatively recent (Valkenburg, 2000) having only been 'primed' by an important publication in the early '80's (Schön, 1983).

The constructivist paradigm acknowledges the way that designers actually operate in the field. However, the positivist paradigm provides the stable 'design methodology base' upon which new tools and methods are more easily based. Both definitions have validity in this research.

Technical or business processes

Roy et al. (1996) identify a fourth way that design process descriptions vary. They state that there is a split between those that have an emphasis on technical aspects and those that focus on business aspects. The technical descriptions tend to emphasize the activities of designers and engineers, where the business ones tend to emphasize management and marketing activities. An example of a model with a technical focus is the 'Systematic approach to the Design of Technical systems and products' by the German professional engineers' body (VDI 2221, 1987). An example of a model with a business focus is the 'Stage Gate Model' by Cooper (2001).

Although this thesis is interested in the activities of designers and engineers, the inclusion of business aspects is crucial to improving any project's chances of success. This chapter looks at how to support the generation of appropriate solutions that have the potential to be taken up in industry, thus a realistic model of the process should include interactions with the 'world' outside the field of design, such as management and marketing.

5.1.4 Simplified generic model of the design process

One of the aims of the thesis is to contribute creative approaches and structured methods which integrate non-intrusively into existing team design practice. Models of the process which are easiest to apply to this thesis therefore need to be based on the *activities* that take place in design.

To create a simplified model for the analysis of the tools in section 5.6 terms were collected which describe the activities in a variety of processes. The terms are laid out sequentially in table 5.1 but came from sequential *and* iterative processes. The brackets show where the authors grouped some of the activities.

Cross, (1994) '4 stage model of the design process'	Cavalucci, (1999) 'four C development process'	Knot, (2001) 'key design process elements'	Roy et al., (1996) 'general model for innovative prod. dev.'	Archer, (1984) 'three-phase design process model'
Explore Generate Evaluate Communicate	Communicate Create Construct produCe	Analyse Understand Decide Create Capture	Plan Specify Research Design Develop Manufacture Sell	Programme Collect data Analyse Synthesize Develop Communicate

Table 5.1: Activities described in various design process models

To develop solutions with the potential to be taken up in industry, the approach needs to be based on a model of the design process which includes the implementation stages. From the overview shown in table 5.1 there are clearly two types of models: those that end with the 'communication' of a final design (Cross, 1994; Knot, 2001; Archer, 1984) and those that go through to the implementation stages of a project (Cavalucci, 1999; Roy et al., 1996).

The model developed by Roy et al (1996) was selected as a simplified generic model of the design process for reviewing the tools in section 5.6. This model was chosen partly because implementation stages are included, and partly because it was based on a significant review of models and is therefore already a generic model.

5.2 Management of design processes

This section looks at what design management factors are required to get innovative ideas through to implementation stages; summarising key points from design management literature.

The Design Council (2002a) states that to direct an innovative project through to market, design management must concentrate on its implementation from the beginning. This can be stimulated by giving all participants involved a clear understanding of the design concept to be developed and their role in delivering it. Their second recommendation concerns the management of ideas and concepts. The design process employed must foster creating and evaluating ideas, enabling iterative alterations to the product concept if necessary. Practical ways of doing that are: setting realistic milestones, acknowledging cost implications and how the ideas will impact on the business, checking feasibility with prototypes, models and user simulation.

The management of design forms the crucial link between those conducting the design activities and the rest of the company. Bruce (1992) highlights the particular need for a two-way link between design and marketing. Designers need input from marketing to design the right product and marketing managers need to create an environment that nurtures design. Cooper and Press (1995) recommend an over-arching organisational structure which links design management with the company's marketing and technology strategies.

If done badly, design management can be harmful and can even prevent innovative ideas getting through to the implementation stages. Walker (1993) states that managers need to understand the delicacy of the design process and the different contributors. The management structure must nurture creative outcomes. He recommends a less-interfering, less-bureaucratic management structure and increased patience and tolerance for this delicate, creative process.

Cooper and Press (1995) summarise the organisational aspects identified by various authors as contributing to successful innovation in business: a matrix- or team-based organisational structure; free time for explorative activities; a participative and collaborative leadership style; and supporting ideas from anywhere in the organisation.

5.3 Management of innovation processes

This research needs to establish what is understood by innovation processes. The words innovation and design are quite often used inter-changeably and definitions of innovation are sometimes synonymous with descriptions of new product development. However, this section explores the management of innovation specifically and summarises the theories for good practice. These are used in section 5.5 as selection criteria for the structured tools and methods reviewed in section 5.4.

5.3.1 What is innovation

The word 'innovation' can be used to describe the act of innovating *or* to describe the end-result of the activity - something newly introduced such as a new method or device. Most authors are interested in the act of innovating, for example, Freeman (1974) describes innovation as: '...the technical, design, manufacturing and commercial activities involved in marketing a new - or improved – product'. Similarly, Roy (1995) describes innovation as: '...the initial commercial introduction - or adoption into use - of a developed and marketed invention'.

Design and innovation

It is useful to explore the role that the design activity plays in getting an innovation to market. Thackara (1997) defines the relationship between innovation and design as: 'design is an instrument of innovation; design is a process that transforms raw technology into products or processes that people can actually use.'

A recent book by Bruce and Besssant (2001) discusses the strategic role that design plays in successful innovation. The aim of their book is to show that design is not just for creative contributors, isolated from the rest of an organisation. Design is a process with a large number of participants, which can, and must, be managed effectively if it is to add maximum value: good design management and innovation success are closely linked.

Objectives of Innovation

Setting descriptions of the end-results expected - objectives - may be an important part of achieving successful innovation. These objectives are normally based on what the users will experience as the end-result.

Some definitions of innovation reflect this user experience as the objective of innovation. The Design Council web site defines innovation as 'introducing new and exciting products/services that exceed market expectations.' Thackara (1997) defines innovation as 'the commercialisation of a technologically changed product in such a way that it improves the service to the user, and secondly, that there is an improvement in the way the product is produced'.

5.3.2 The innovation process

Similar to the design processes reviewed in section 5.1.3 there are different ways in which innovation processes have been commonly classified.

Incremental or radical processes

Incremental innovation is the process by which products evolve gradually with regular implementation of new technologies. Radical innovation tends to involve the commercial introduction of something completely new that has not been thought of before. The problem with these two categories is that there are no distinct boundaries between them. A company's innovation strategy may be referred to as either incremental or radical, but in practice it may be hard to distinguish between them.

Most writers acknowledge both radical and incremental innovation as valid forms of innovation theories (Rothwell, 1992; Roy, 1995). Incremental innovation is perhaps less risky than radical innovation. Incremental innovation is more likely to be seen as a sound business practice. Thackara (1997) for example, supports incremental innovation and comments that: 'Successful companies reinvent their products continuously. All the time. Every minute of the day. Not in big bangs, but in thousands of little steps.'

The aim of this thesis is to contribute to the research in 'step-change' or 'radical' environmental innovation that is required to move towards more sustainable production and consumption modes. The main driver for this 'step-change innovation' strategy is that environmental problems are continuing to increase and that today's incremental improvements are not reversing the destructive effects on the environment fast enough (see section 1.1.2). This thesis sets out to identify tools and methods that will support such a radical innovation strategy, but that are based on a realistic industrial model of the design process and can be integrated non-intrusively into existing team design practice.

Technology push or market pull

The second way that innovation processes can be differentiated are the technology-driven processes and those that are driven by market demand. This analysis of innovation processes is a recent phenomenon, and by looking back at the last five decades it is possible to see the rapid change in the models of innovation (Rothwell, 1992).

The first major shift in perspective took place in the 60's when markets and consumers' needs were first acknowledged as forces driving innovation - market pull. Before then, technology had been seen as the only major driving force - technology push. In the market pull model, research and development (R&D) plays an almost reactive role to the demands of society.

In the 70's the 'coupling model' emerges, acknowledging the roles of both technology and market. This model describes the balance between the external factors - technology push and market pull - and the internal new product development process that creates successful innovation.

In the early 80's another model emerges that attempts to streamline the innovation process by managing parallel processes. This model emerged at about the same time as similar concurrent models of the design process described in section 5.1.3. These parallel models require more intensive management and have led to the development of electronic tools that attempt to link the three parallel activities of R&D, prototyping and production development.

The last innovation model described by Rothwell (1992) is his own Strategic Integration Networking (SIN) model. In this model, innovation is not only managed within companies - 'innovation friendly' structures and clear innovation strategies - but also external strategic alliances are made. As more external actors become involved, management of the process becomes even more demanding. There is evidence of this model in environmental management too, as consultants are now running training courses in new subjects such as 'innovative supply chain management'.

5.3.3 Reducing innovation risk

Managing innovative product development is acknowledged by various authors as a difficult and fundamentally complex activity (Baxter, 1995; Cooper and Press, 1995). The main reasons cited for this are the uncertainties about future markets and technology. Management decisions will often need to be based on factors which are difficult to predict.

Whilst innovative product development is almost always seen as a high-risk activity, it is also becoming accepted that innovation is crucial for commercial survival. Cooper (2001) states that innovation is 'the key to corporate prosperity'.

Companies want to assess and measure the risks involved and establish the 'success factors' for innovative product development. However, some benefits of innovative design remain un-quantifiable. Thackara (1997) states that one of the challenges is to demonstrate how and by how much innovative design works better than indifferent design. Innovation management is developing methods to assess and measure innovation risks.

Apart from this reactive approach several authors offer texts to help designers and managers pro-actively reduce the risk involved in innovative product development. Baxter (1995) lists a number of things that *can* be done:

- The development of new products can be budgeted, timetabled and quality-controlled;
- Costs of failure can be contained by identifying unsuccessful products early;
- Reasons can be found why some innovations succeed whilst others fail.

Baxter suggests a two-part approach to reducing innovation risk. The first part is a structured *framework* for the innovation process, similar to those reviewed under the design process (section 5.1.3), often sequential and prescriptive models. The second part consists of the systematic design and development *tools* which help stimulate ideas, analyse problems and structure design thinking. Baxter (1995) states that systematic design and development tools are still not used to their full potential in industry.

Systematic design and development tools formalise procedures in design and externalise design thinking (Cross, 1994). Formalising procedures helps to avoid oversights and widens the approach taken to the problem, thereby reducing the innovation risk. Externalising design thinking helps communicate ideas and concepts within development teams and helps deal with complex problems.

5.3.4 Differences between design management and innovation management

Due to the overlap in the terms 'design management' and 'innovation management' in the literature, it is hard to distill a consensus on the differences between them. Perhaps some differences between design management and innovation management can be identified by looking at the elements that exist in companies with particularly innovative cultures.

The Design Council (2002b) lists two crucial elements that make up a thriving innovative culture: first, the ability to inspire staff and second the ability to connect effectively with customers and markets. Walker (1993) stresses that to establish an innovative culture in a company, managers will have to pro-actively foster those elements.

One concrete aspect that makes innovation management different is that the process will almost always include a significant R&D stage early on, sometimes referred to as a feasibility study (Roy et al., 1996). This R&D consists of focused, original work to acquire the knowledge needed for the development of the new product.

5.3.5 Summary of theories for good practice in innovation

From the literature, the following theories for good practice in innovation have been summarised - in the form of statements - describing the criteria that the design tools must adhere to if they are to be taken further in this study. The first three are the most relevant issues for this research and are taken further in the following chapters. However for the purposes of this chapter all the criteria will be used in section 5.5 to review the tools selected.

Be able to support a radical innovation strategy.

If design tools are to be employed, they must be able to support a radical innovation strategy rather than an incremental innovation strategy. Significant 'step changes' are the aim of this research because there is a need to speed up and increase the extent of environmental improvements. Environmental design has thus far provided mainly incremental environmental improvements to products and services.

Support design at the system level.

If tools are to be employed, they must support design at different levels and be flexible enough to be applied at detail, product, system or strategic levels. Successful innovation is dependent on good decisions at all these levels, which reinforces the calls in environmental design research for a shift from a product-focused design activity towards system-level innovation (as discussed in sections 1.1.4 and 1.2.2)

Focus on the design or problem-solving aspects of the process

Chapters 3 and 4 of this thesis investigated improving eco-innovation through facilitating and improving the capture of idea output at the early stages of the process. Hundreds of idea-generating techniques exist, which unleash creativity and remove mental blocks, to increase idea output. However, a large idea output does not necessarily help participants translate these ideas into appropriate solutions that have the potential to be implemented. Therefore, this part of the thesis does not look further into these creativity techniques but instead looks at design tools that focus on design or problem-solving aspects of the process. The tools selected for review should move ideas towards implementation by helping to identifying the problems and by having problem-solving capability.

Balance the influence of technology and the market.

If design tools are to be employed they must take into account both the influence of new technologies and the market demands. Successful innovation is the result of balancing these external factors and managing the new product development process.

Offer alternatives for changing direction at all stages of the process.

If design tools are to be employed they must offer alternatives for changing direction at all stages of the process. Baxter (1995) advocates a process for innovation where a quantity and range of ideas, concepts and strategies is generated at all stages. Selecting the best from them at each stage provides a sound innovation strategy.

Speeding-up the development process and making it more efficient.

If design tools are to be employed they must speed up the development process and make it more efficient. This can be promoted by cutting out iterations or stages in the process and promoting a concurrent development process. Conventional processes need to be replaced by team-based, concurrent processes where R&D, prototyping, and production development occur simultaneously.

Identify and eliminate unsuccessful ideas early.

If design tools are to be employed they must help identify and eliminate unsuccessful ideas early. Cooper (2001) recommends a systematic innovation process with 'stage-gates' where Go/Kill decisions have to be made. Baxter (1995) recommends that clear, concise, specific and verifiable targets are first established for the project. Subsequently, the emerging new product ideas, concepts and strategies are compared to the targets and killed off quickly if it becomes apparent that they will not reach those targets.

5.4 Review of tools and methods for structuring innovation

From the literature reviewed in this study it has become clear that there are hundreds of systematic design and development tools available. Some examples of common tools and methods are:

> Orthographic analysis, Ansofs matrix, Strengths Weaknesses, Opportunities Threats (SWOT) analysis, Product life-cycle curves, Strategy-Resource fit, Benchmarking, Delphi methods, Evaluation matrices, Quality Function Deployment (QFD), Product Design Specification (PDS), Six Sigma, Theory of Inventive Problem Solving (TRIZ), Failure Modes and Effects analysis (FMEA),

Fault Tree Analysis (FTA), Value Analysis, Value Engineering, Axiomatic Design, Taguchi methods, Theory of Constraints, Viable Systems Model, Multi-Criteria Decision Analysis (MCDA), Design for Manufacture and Assembly (DFMA), Morphological charts, Synectics, Functional Analysis, Objectives Tree method, Parametric analysis, SCAMPER, Life-cycle analysis, Concurrent engineering, Fundamental design method, Attribute listing, Consensus mapping, Program Evaluation Review Technique (PERT), Creative problem solving (CPS).

Practitioners from a variety of disciplines: designers, engineers, psychologists, marketers, managers, researchers and academics have developed these tools. Such tools can be found in books on: new product development, innovative product development, engineering design, innovation management or problem solving. Different authors have reviewed, selected and grouped the tools in different ways.

Baxter (1995) presents 24 tools and groups his 'tool kits' according to the innovation stages which he defines as: product development strategy; opportunity specification; concept design; product planning; and detail design. He also provides a separate category for tools which 'improve creative thinking procedures'.

Cross (1994) describes two basic types of tools - creative and analytical - and describes them as complimentary aspects of a systematic approach to design. He presents 7 specific tools within the following sequence of a design process: clarifying objectives; establishing functions; setting requirements; determining characteristics; generating alternatives; evaluating alternatives; and improving details.

Jones (1992) presents 35 tools and groups them according to the activities that occur in the process: exploring the design situation; searching for ideas; exploring the problem structure; and evaluation. He also collected methods which assist designers at the strategic level - 'prefabricated strategies' and 'strategy control methods'. Those tools help decide what actions need to be taken to transform the brief into a final design.

Zusman and Zlotin (1999) reviewed 97 tools and describe development processes as requiring: creativity, problem solving and design. They say that the tools reviewed have all been developed to support these three activities to different levels of detail. They created a matrix overview of the methods reviewed, classifying the techniques as follows: conditioning/motivating/organizing, randomising, focusing, systems, pointed, evolutionary-directed, or innovation knowledge-based.

VanGundy (1988) is another author who presents many methods – 84 - and organises them according to a model of a problem solving process. The main problem for this study is to select a manageable number of potentially useful tools to review. He confirms that there is little research evidence to support the selection guidelines for tools or even comparative research on the usefulness of the different tools themselves. He offers some selection guidelines based on the anecdotal reports from practitioners who have used many of the techniques. Jones (1992) lists his criteria for including methods in his book - effectiveness, relevance, convenience, familiarity and criticism - but admits that his selection was made based largely on his own experience and the literature about the methods themselves.

Initially, ten tools were selected for this study from the long list, by looking at some of the overlap of selections made by other authors: Cavalucci and Lutz (2000), Baxter (1995), Cross (1994), Zusman and Zlotin (1999), Mann (2000b), Roozenburg and Eekels (1995), Jones (1992) and VanGundy (1988). Those ten tools were: Value Engineering, Evaluation matrices, QFD, TRIZ, FMEA, Axiomatic Design, Taguchi Methods, Morphological Charts, Synectics and Functional Analysis. From those ten tools the following three were eliminated for the following reasons:

- <u>Synectics</u> is a method designed to give more structure to brainstorming sessions. It is mainly a method to increase idea output and not a design-focused or problem solving method.
- <u>Axiomatic Design</u> is an abstract and conceptual study of good engineering practice consisting mainly of theory to improve the engineering discipline.
- <u>The Taguchi Method</u> is a quality control tool which has thus far centred on improving - in monetary terms - existing products or processes for a specific product.

The seven tools left are reviewed and summarised in the following section.

5.4.1 Seven potentially relevant methods

Value Engineering (VE), (main author Miles, 1961)

VE was developed by Miles at the General Electric company in the 40's. VE is a technique especially useful for technical problem solving in organisations. In most cases the method will lead the ideas developed through to implementation.

The most common aim for VE is to increase or maintain the value of a product to its purchaser whilst reducing its cost to its producer. VE can also be used to seek ways of adding new value to a product; however, the aim is always to increase the value/cost ratio.

The method consists of 5 steps.

1. The product components are listed and the function served by each is identified. For the development of a completely new product it will be necessary to use a hypothetical or 'typical' version of the proposed new product.
2. The values of the identified functions are determined. This is the difficult stage of the process where the designer must try to quantify the perceived values or benefits of the components functions - normally based on detailed market research.
3. The cost of components is determined. This can be a bit difficult, depending on the costing information available from different departments/disciplines. The proportional costs of components relative to the total product cost should also be calculated.
4. Ways to improve the value/cost ratio are sought. This stage requires critical thought about what the product is and creative thinking about what it might be. The method provides three strategies, a five-point checklist of cost-reduction guidelines and a list of common quality/value attributes.
5. Alternatives are evaluated and improvements are selected. The process should result in a number of new alternatives. The compatibility and validity of those options must be evaluated.

Evaluation Matrices (main author Pugh, 1997)
These matrices are intended to improve concept formulation and selection. It may not be possible to evaluate all ideas during the course of a project, but this method offers a progressive and disciplined way of reducing risks at the evaluation stages of a process.

The matrix provides a way to score multiple solution concepts; from the matrix it becomes possible to select the concepts that can be taken further. The matrix can also be used creatively by highlighting the areas for potential improvement of the concepts.

The method consists of 5 steps:
1. Concepts for the product are sketched in boxes across the top of the matrix. Concepts should be at a similar level of development.
2. A datum concept (normally the concept expected to be the best) is chosen against which to compare the other solutions.
3. The criteria against which the solutions are compared are listed down the left hand side. Depending on the development process followed, these may be extracted from earlier specifications drawn up, or other inputs such as those from marketing.
4. The concepts are scored against the datum concept: + (better), -(worse) or s (same). These scores can be weighted to reflect their relative importance.
5. The scores are added up and conclusions are drawn.

Quality Function Deployment (QFD), (main authors Hauser and Clausing, 1988)
QFD is a systematic process that helps users understand and integrate their customers' needs into the products they are developing. It is normally used to support the process from problem identification to design specification. The fundamental principle of QFD is to gather all relevant information about the customer, 'the voice of the customer', and use this information to drive the design of a product. This type of information tends to feed incremental product innovation.

QFD presents useful information to the whole team involved in the design and manufacturing processes from beginning to end. It is therefore particularly useful in concurrent development processes. It allows specialists to contribute to the specification and a large amount of information to be condensed into a relatively a small number of documents or charts.

The method consists of 9 steps:

1. An overview of desirable product attributes is created. These can be based on precise or less rigorous data from: consumer research, existing internal knowledge, complaints, or trend analyses. These attributes are then weighted according to their relative importance.
2. The company's existing product is benchmarked against the best competitors product on the market. The product is scored 'better', 'similar' or 'worse' on the attributes from step 1.
3. The project objectives are based on the opportunities for improvement made explicit in step 2.
4. The new product is described in terms of engineering characteristics called 'technical parameters'. These parameters must be measurable.
5. The 'interaction matrix' is created. This is the core of QFD, where technical parameters are linked to the desired product attributes in a matrix. The project objectives (step 3) set the priorities for the technical parameters.
6. The 'roof of the house of quality' is created. The nature and strength of the interactions between the different technical parameters is made explicit in this matrix, which is attached to the interaction matrix.
7. The insights into the possibilities for improvements have been attained and the target values for future products can be set.
8. A feasibility check and an estimate of the complexity and costs for the target improvements is made.
9. A development plan or design specification for the new product can now be drawn up. The technical parameters which do not prove feasible for the current project can be passed to R&D for investigation. This secondary output from QFD is of long-term strategic importance.

Theory of inventive Problem Solving (TRIZ), (main author Altshuller, 1984)

TRIZ has been developed in several stages over the last 50 years. Its development began with Genrich Altshuller in the former USSR who hypothesized that universal principles of innovation existed and could be identified. Today, over 2 million patents of technical innovation have been examined in order to discover principles and theories for innovation.

From the extensive research conducted, several primary findings were discovered regarding: patterns of problem and solutions, the elimination of contradictions and patterns of technical evolution.

Along with the primary findings, the principles of good inventive practice were distilled. These take the form of knowledge-based tools (about six) and analytical tools (about four) which are used to structure and solve innovative problems. These specific techniques make up a versatile innovation toolbox based on the underlying findings and the basic TRIZ problem solving process.

Although TRIZ was originally developed to solve technical inventive problems it is generally applicable to any system that can be defined. TRIZ contains both tools and principles which can benefit all aspects of innovative product development.

The basic TRIZ problem solving process consists of 4 steps:

1. A specific inventive problem is abstracted using the analytical tools in order to establish the generic problem.
2. The generic problem is solved using the knowledge-based tools to provide generic solutions.
3. The generic solutions are then 'translated' into specific solutions for the original problem. This is an analogous process.
4. The specific solutions are evaluated against the original specific inventive problem defined.

Failure Modes Effects Analysis (FMEA), (main author O'Connor, 1991)
FMEA was developed as a tool to enhance 'right first time' design methods and to speed up a product's 'time to market'. The tool can significantly reduce the risk of failures and quality problems with innovative new products.

FMEA was developed as way of identifying potential failures which might occur from the use of the product, instead of failures that might occur due to individual components. The method looks at the product functions from a user's perspective and exposes the failure modes - ways in which it could fail to perform those intended functions.

Generally FMEA leads to slight revisions in designs close to the manufacturing stages. However, if major flaws in the concept are revealed, designers may be forced to abandon a problematic design and go back to alternative product concepts for development.

FMEA consists of nine steps which are normally laid-out in a simple matrix:

1. An analysis of all the product's functions is conducted from the user's perspective.
2. Several failure modes are identified for each function (2 or 3 word statements).
3. Several potential causes are described for each of the failure modes (2 or 3 word statements).
4. The likelihood of such an occurrence is scored between 1 (practically never) and 10 (almost always).
5. The effect – consequences - of each failure, as perceived by the user, is described and forms the basis for the severity score which follows.
6. A descriptive severity-ranking table is created and the severity of each effect is scored between 1 (inconvenient) and 10 (worst case).
7. A realistic verification procedure to detect the failure before the product reaches the market is described.
8. The likelihood of detecting the failure with the verification procedure is scored between 1 (almost certain to be detected) and 10 (almost impossible to detect).
9. The risk priority number is calculated by multiplying the occurrence, severity and detection scores. This score amplifies the risks to the producer, as the consequences of high scores will cumulatively affect their reputation. The risk priority number will stimulate corrective action.

Morphological Charts, (main author Zwicky, 1969)
Morphological Charts were developed to help identify novel combinations of elements or components in design. However, the general principle of the tool can be used on any type of problem, including social, organisational, marketing or management problems.

The tool divides a problem into its major parameters, components or problem dimensions and then systematically allows the user to identify all the combinations possible with those elements. These are sometimes called 'forced relationships' and help the user find all the theoretically conceivable solutions to a problem. The method creates detachment from preconceived possibilities and separates the activities of creating and evaluating ideas.

The tool can be used at any stage of the development process, but it is mainly used to analyse the problem, generate ideas and implement solutions. The main problem with the method is that the number of conceivable solutions to a problem needing to be analysed, increases exponentially as the number of axes, parameters and components increase. The Morphological Charts can be two- or three-dimensional and the number of parameters or components on the axes needs to be kept to a minimum (normally somewhere between 3 and 7). Identifying the parameters and components, and keeping the number of these down is perhaps the most difficult part of the method.

The method consists of 4 steps:
1. Two or three major problem dimensions are identified. Common examples of two-axis models are: components versus parameters or functions versus means.
2. All the relevant sub-divisions for each dimension are listed, such as the functions that are essential to the product, or the parameters which might occur in the solution. These should be described at the same level of abstraction and should be independent of each other.
3. A 2-dimensional matrix or 3-dimensional cube is used to list all the connections possible between elements. Computer programs, sliding linear or concentric cardboard models can speed up combining the different elements.
4. All the combinations generated are evaluated by eliminating impractical or impossible combinations and selecting likely solutions based on previously established criteria.

Functional Analysis (main author Hubka, 1982)
Functional analysis is treated as a method, even though it is hard to identify its exact origins and several authors describe the method from slightly different theoretical points of view. However, there is general consensus on the aims and implementation of the method.

Functional analysis describes the functions of a product and its constituent parts and indicates the mutual relations between them. It can be used pro-actively to specify what a new product should do and to infer what parts and interactions are therefore required. This method helps to develop the essential characteristics required of the new product, and to describe the system boundaries for the project. New possibilities will emerge by shifting the system boundaries.

The method uses abstraction of the system to help the designer view the project from a broader perspective. It is good at creating and comparing alternatives for the structure of a new product. The system's functions must provide the transformation of the environment - situation - from the 'initial state' to the 'desired state'. Three fundamental variables can act on the system: matter, energy and information.

The method consists of 5 steps:
1. The new product is defined as a 'black box', in which 'inputs' are transformed into the desired 'outputs'. This requires fundamental questioning of the purpose of the new product. This questioning widens the system's boundary and opens possibilities for radically new solutions and concepts.
2. The black box needs to be broken down into a set of essential sub-functions. These should be expressed as simple 'verb-noun' statements. Each essential sub-function has its own inputs and outputs which need to be listed.
3. A block diagram is drawn showing how the sub-functions (inputs and outputs) are linked. The inputs and outputs will show the flows of matter, energy and information in the system. The designer is creating a functional system, and may therefore have to redefine some of the sub-functions and experiment with different layouts.

4. Within the block diagram a system boundary is drawn; this determines the development focus for the rest of the project. Experimenting with different system boundaries will create different solution directions. However, normally the system boundary will be influenced by management or marketing strategies.
5. Finally, sub-functions are translated into real components. Different types of components may be investigated for each sub-function. Possible examples include mechanical components, an electronic device or a human performing a task. This stage may include splitting or combining sub-functions to specify a feasible device.

5.5 Summary of tools in relation to best-practice innovation

In this section the tools reviewed in section 5.4.1 have been scored against criteria for good innovation practice distilled from section 5.3.5. Some of these criteria overlap with the attributes from the eco-innovation model (described in section 1.2.2). This makes those criteria more relevant to this research. The criteria distilled are shown in table 5.2 in approximate order of relevance to this research. The first two criteria were identified as most relevant to this research and have therefore been given a double score.

	Value engineering	Evaluation matrices (Pugh)	Quality Function Deployment (QFD) (Akoa)	TRIZ Theory of Inventive Problem Solving (Altshuller)	FMEA (Failure Modes and Effects Analysis)	Morphological Charts (Zwicky)	Functional Analysis
Be able to support a radical innovation strategy *		XX		XX	XX	XX	XX
Support design at different system levels *			XX	XX		XX	XX
Focus on design or problem-solving aspects of the process	X			X		X	X
Balance the influence of technology and the market	X	X	X		X	X	
Offer alternatives to change direction all stages of the process	X	X	X	X		X	X
Speeding up development process and make it more efficient	X	X	X	X	X		X
Identify and eliminate unsuccessful ideas early	X	X	X	X	X		X
Key: x= tool fulfills criterion xx= tool fulfills criterion (double score) * = criterion prioritised for eco-innovation							

Table 5.2: Potential improvements in innovation practice from the use of tools

Table 5.2 shows the outcomes from this study, a crossed box indicates whether the tool reviewed offers potential improvements in that aspect of innovation practice. Many of the tools score positively for several criteria and are likely to improve the process of innovation if compared to a development process without such tools in place. The *extent* to which the process is improved by each of the tools cannot easily be estimated and falls outside the remit of this study.

Authors tend to have different opinions on the effectiveness of the tools, although it is agreed that different tools suit different types of projects. In table 5.2 boxes were left blank when the tool's literature did not contain any reference to that criterion. This table only provides a basic idea of the intentions of each of each tool. From this crude summary the tools that scored highest were Functional Analysis, Morphological charts and TRIZ.

This chapter set out to identify tools that can aid the development of appropriate solutions. Reviewing the literature will only provide a rough idea of the different tools' intentions. To assess the tools' potential to improve eco-innovation, the tools need to be tried out. To achieve the depth of research required, one promising tool or method will be selected for further investigation in the following chapters.

5.6 Summary of tools in relation to the design process

Various authors have looked at tools in relation to the design process before. Cross (1994), for example, describes how the tools can be selected based on the 'management framework' – or model of the design process - within which the tools are used. Each stage of the design process comes with recommended methods. Jones (1992) developed extensive flowcharts for the selection of appropriate tools at the different stages of the design process.

This research focuses on the early stages of eco-innovation. However, this chapter looks at the tools that can support a range of activities that may provide solutions that are more likely to be taken up in industry. This section looks at the different *activities* that the tools can support throughout the process. The activities that make up the criteria used in table 5.3 are taken from the generic design process selected in section 5.1.4.

Several of the tools selected for review *evaluate* concepts prior to the commitment required for implementation. It was therefore useful to add that activity to the matrix. Also, the stage labelled 'develop' was too vague to be useful. It was decided that the term 'develop' in this case would mean the specific development activities prior to implementation. Examples might be activities such as detail design or prototyping. The final collection of activities used as criteria to review the tools were: plan, specify, research, design, evaluate, develop, manufacture and sell.

	Value engineering	Evaluation matrices (Pugh)	Quality Function Deployment (QFD) (Akoa)	TRIZ Theory of Inventive Problem Solving (Altshuller)	FMEA (Failure Modes and Effects Analysis)	Morphological Charts (Zwicky)	Functional analysis
Plan				x		x	x
Specify			x	x		x	x
Research	x		x	x			
Design	x			x		x	x
Evaluate	x	x			x		
Develop				x		x	
Manufacture				x			
Sell							
Key: x= tool supports activity							

Table 5.3: Activities that the tools reviewed can support

Table 5.3 summarises the outcomes from this study. The boxes crossed indicate which activities the tools are intended to support. The simpler tools tend to be those that focus on one specific activity in the process. The tools that spanned the largest number of activities of the process are the more complicated tools. TRIZ covers the largest number of activities, because it is the only method reviewed that contains several specific tools as well as an underlying theory for inventive problem solving.

5.7 Conclusions

This chapter has reviewed the management of design and innovation, and tools from mainstream practice, to inform this research on improving eco-innovation. A selection of tools and methods has been investigated for their potential to improve the process of innovation and support the different types of activities in the process. From the selection matrices in sections 5.5 and 5.6 TRIZ has been identified as an approach that warrants further investigation.

This chapter has shown that TRIZ provides a problem-solving approach which can support radical innovation and design at different system levels. TRIZ contains numerous specific tools as well as an underlying theory which could provide improvements across most activities in the design process.

During this review other points emerged which strengthened the case for further research into TRIZ for eco-innovation:

- TRIZ may be complimentary to the PIT diagram by helping to translate ideas from the enlarged solution space into more appropriate solutions that have the potential to be implemented.
- TRIZ has only recently been introduced outside the former USSR and has had limited exposure in environmental design research. TRIZ may therefore be of further interest to this research community.
- TRIZ is considered a developing discipline; therefore this work might not only contribute to the environmental design community but also to the TRIZ research community.

The rest of this thesis aims to establish how TRIZ can be adapted and focused to improve eco-innovation workshops in particular. Chapter 6 explores and provides worked examples of TRIZ for use in eco-innovation. Chapter 7 explains the development and testing of simplified TRIZ tools for use in eco-innovation workshops.

Chapter 6 Exploring TRIZ for use in Eco-innovation

The previous chapter showed that TRIZ is a problem-solving approach with great potential for contributing to eco-innovation. It includes numerous specific tools, as well as underlying discoveries which could support radical innovation and design at different system levels. To assess the tools' specific potential for improving eco-innovation, TRIZ needed to be further investigated and evaluated.

This chapter presents several different types of studies which were presented to both the environmental design research community and the TRIZ research community.

Due to the range and diversity of tools in TRIZ it was necessary to create an overview or 'map' of TRIZ, which is presented in section 6.1. The subsequent sections report on the studies conducted. These studies are of three main types: theoretical investigations of TRIZ for use in eco-innovation, practitioners' interviews and worked examples.

6.1 The diversity of TRIZ tools and discoveries

TRIZ is referred to in the literature as a science (Fey & Rivin, 1997), a methodology (Savransky, 2000), a toolbox (Kowalick, 1997) and even a philosophy (Nakagawa, 2001b). An initial exploration of TRIZ reveals an overwhelming number of different approaches and tools described by different authors. Even 'TRIZ masters' trained under the founder G. Altshuller, have developed divergent approaches and a wide range of different tools such as: engineering system forecasting maps (Chuksin & Shapkovsky, 2001), the 9-screen diagram (Seredinski, 2001), the innovative situation questionnaire and anticipatory failure determination (Terninko, Zusman & Zlotin, 1996), to name but a few.

TRIZ consists of three main components: fundamental discoveries on the nature of inventive problem solving; specific innovation tools; and sequential processes, all of which were initially based on the extensive systematic studies of technical and patent information and further studies of the nature of problem solving. TRIZ helps to avoid trial and error problem solving by employing generalised patterns distilled from previous solutions. A second important tenet from TRIZ is that inventive problem solving requires the elimination of contradictions, as opposed to 'design-by-compromise' approaches.

TRIZ is still considered a developing approach. The terms 'classical TRIZ' and 'modern TRIZ' appear in the literature. 'Classical TRIZ' is the TRIZ that was considered finished within Altshuller's lifetime and was based on texts written by himself and his followers. 'Modern TRIZ' introduces the application of TRIZ in new contexts and the adaptation of its tools. Examples of 'modern TRIZ' are: TRIZ applied in the non-technical context (Mann, 2000a; Zlotin et al., 2001); simplified TRIZ approaches such as USIT (Nakagawa, 2001a); TRIZ for business and management (Mann & Domb, 1999, Ruchti & Livotov, 2001) and TRIZ tools combined with innovation tools and techniques such as QFD or Six Sigma (Hipple, 2000; Terninko, 2000, Domb, 2000a).

Classical TRIZ was based on at least 1500 man-years of research (Mann, 2000b), which led to the development of numerous useful innovation tools. It is estimated that only twelve core tools from Classical TRIZ are commonly employed in practice today (Mann, 2002). However, each practitioner develops his own way of combining the tools: using them sequentially or individually. Table 6.1 shows the sequences employed by two industrial practitioners from similar backgrounds and with similar levels of TRIZ expertise. The table shows similar headings for the overall sequence of their problem solving process and similar tools selected. However, the tools are combined in different ways and sometimes employed for different purposes.

Procedure based on Terninko, Zusman and Zlotin (1996), as interpreted and practised by Ian Care (Care & Mann, 2001)	Proceedure followed by TRIZ group at Ilford Photographic ltd., as described by Ian Mitchell (Mitchell, 2002)
Analyse the problem: Functional analysis State Ideal Final Result Resources Locate the zone of conflict Trimming Restate Ideal Final Result Define problem Identify contradictions Physical Technical Effects Prediction Principles Contradiction matrix Idea evaluation Su-field analysis Idea evolution Trends of evolution Patterns Prediction Information Pugh concept selection	Analyse the problem: Look for a similar problem Functional analysis Identify contradictions Contradiction matrix State Ideal Final Result Resource analysis Su-field analysis Smart little people Identify Physical contradictions Separation priciples Solution ideas 76 standards Trends of evolution Su-field resources Effects database If problem unresolved use ARIZ Idea evaluation Incremental / radical changes? Follow evolution trends? Risk?

Table 6.1: Example of sequences employed by two industrial TRIZ practitioners

The following section attempts to create an overview or 'map of TRIZ'. The 'map of TRIZ' presented can be used during the rest of the chapter as a reference guide to the TRIZ terms used.

6.1.1 Map of TRIZ

The map, shown in figure 6.1, is divided into three main segments: fundamental discoveries about the nature of inventive problem-solving, specific innovation tools and sequential processes. The tools segment is then sub-divided into two segments: tools to overcome mental inertia and problem-solving tools. In turn, the problem-solving tools are divided into problem analysis tools and solution tools.

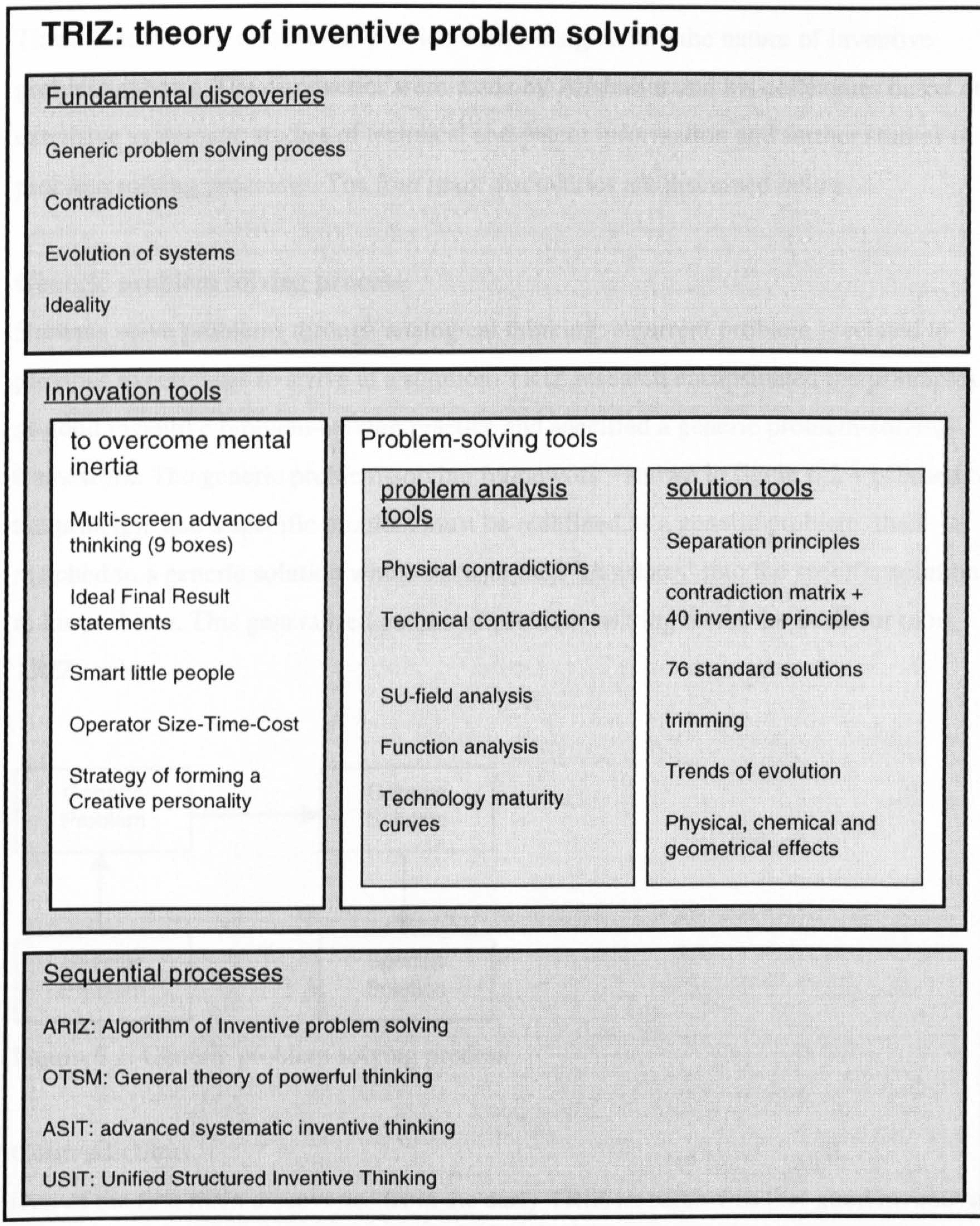


Figure 6.1: Map of TRIZ showing sections

The rest of this section explains the segment headings and sub-headings, and how the tools have been grouped in the Map of TRIZ. Due to the size of the method, it is easier to provide a separate glossary of specific tools, which can be found under section 6.1.2.

Fundamental discoveries

These fundamental discoveries provide useful insights into the nature of inventive problem solving. The discoveries were made by Altshuller and his colleagues based on extensive systematic studies of technical and patent information and further studies of problem solving processes. The four main discoveries are discussed below.

Generic problem solving process

Humans solve problems through analogical thinking: a current problem is related to previous experiences to arrive at a solution. TRIZ research encapsulated the principles of good inventive problem-solving practice and specified a generic problem-solving framework. The generic problem-solving framework - shown in figure 6.2 – is based on the principle that a specific problem must be redefined as a generic problem, then matched to a generic solution which the user then 'translates' into the specific solution to his problem. This generalised pattern of problem-solving forms the basis for most TRIZ tools.

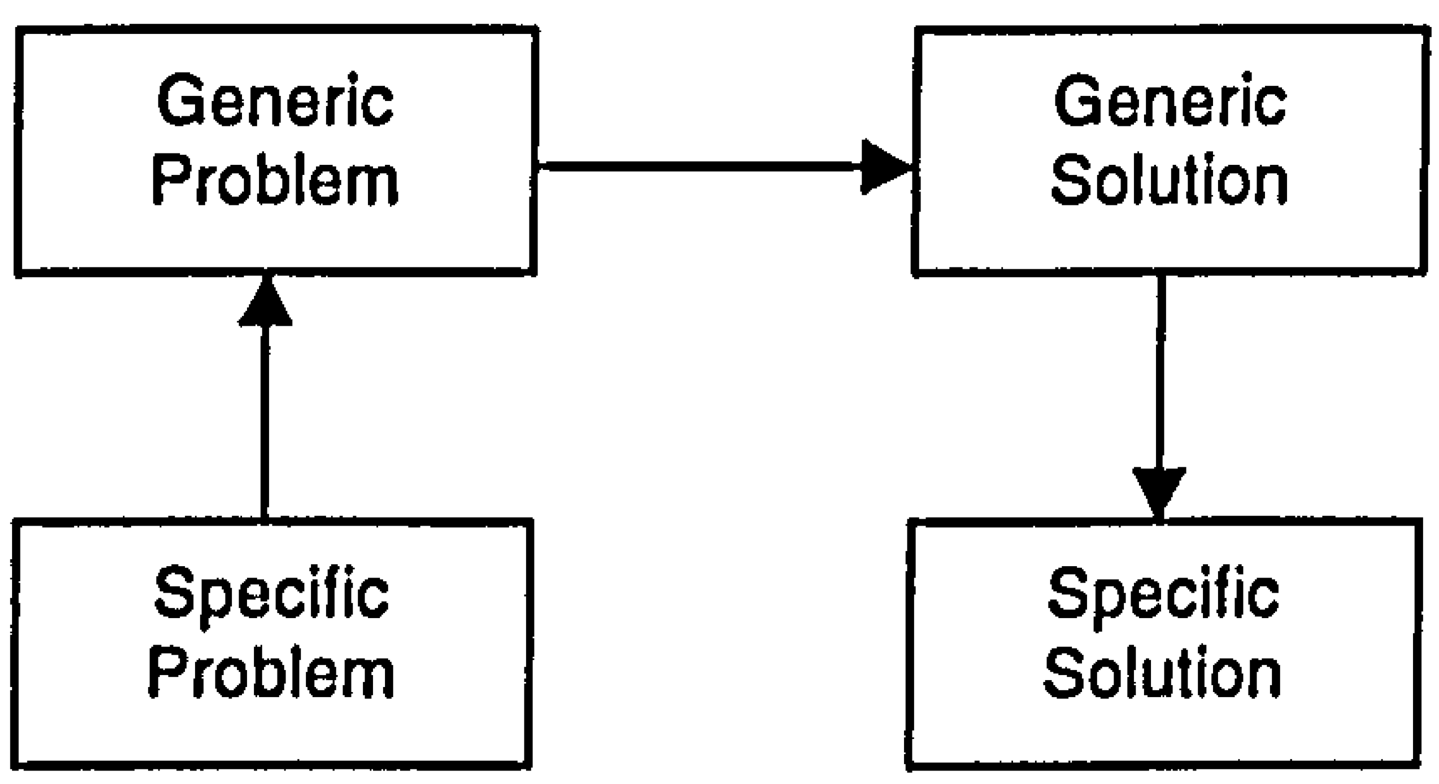


Figure 6.2: Generic problem solving process

Contradictions

One of the first main discoveries from the early TRIZ research was that good inventive practice often involved the elimination of contradictions. Designers are traditionally trained to optimise *compromises* between conflicting parameters. TRIZ practice is based on seeking out the conflicts and contradictions and attempting to *eliminate* them instead. TRIZ makes bold statements against the culture of 'design by compromise' in design and engineering.

Evolution of systems

Through the study of generalised patterns of problems and solutions, TRIZ researchers discovered generic regularities and patterns of technology evolution. These documented patterns, the eight laws of evolution of technical systems (Altshuller 1984), have subsequently been developed and expanded into tools in their own right, such as the 'technology evolution trends' (Invention Machine, 1995), 'patterns and lines of technological evolution' (Ideation International, 1998) and 'trends of evolution' (Creax, 2002).

Ideality

The concept of ideality is one of the eight laws of evolution of technical systems discovered. This particular law is classed as a fundamental discovery of TRIZ because of its importance to good inventive practice. The law states that systems will evolve towards *ideality*; where the function is performed perfectly but the physical system disappears altogether. Ideality can be expressed as a qualitative equation of benefits divided by the sum of costs and harms.

$$Ideality = \frac{benefits}{(costs + harms)}$$

Ideality would be achieved when the benefits approach infinity (∞) and the costs and harms approach zero (0). Although ideality may be an unrealisable goal, the theory is often used to drive the design closer to an 'ideal final result'.

Innovation tools

This is the 'toolbox' section of TRIZ; the tools developed have been based on the fundamental TRIZ discoveries. The selection of tools shown in figure 6.1 is by no means complete, but it presents the most commonly used tools. The following paragraphs describe the headings and sub-headings for the innovation tools.

Tools to overcome mental inertia

The techniques for overcoming mental inertia that TRIZ offers are based on studies done on 'advanced' or 'visionary' thinking versus traditional ways of thinking. Two important observations were made on 'advanced' thinking: the interrelations between other problems and the system are identified by the practitioner; and the practitioner is able to produce causal relationships between the system and its environment (Souchkov, 1999). The TRIZ techniques to overcome mental inertia improve the user's way of thinking about the system. These tools are similar to well-known techniques such as morphological analysis or attribute listing; they force the user to widen his perspective on the problem and widen his search for ideas.

problem solving tools

The problem solving tools are based on the generic problem solving process described in figure 6.2. The problem analysis tools are used to generalise the problem. The solution tools use the generalised problem to create a generic solution. If the generic solution does not lead to a suitable specific solution in the first instance, the practitioner will iterate through the process, possibly refine and reformulate the problem using a different tool from the extensive problem-solving 'tool box'.

problem analysis tools

These tools are designed to help the practitioner create his 'generic problem'. The different tools in this category each provide different ways of generalising their problem. These tools are also sometimes known as 'situation analysis tools'.

solution tools

The output from the problem analysis tool selected determines the type of tool that can be used to create the 'generic solutions'. This means that analysis and solution tools are often used in set combinations. Table 6.2 shows common combinations of tools used in current TRIZ practice as reported on the TRIZ journal web site. The table shows three examples for each of the common tool combinations. The solution tools are also sometimes known as 'knowledge-based tools'.

Tool type	Tools used	Practitioner's application	Principal author	Issue of TRIZ-journal
P S	Technical contradictions contradiction matrix + 40 inventive principles	Airbag applications Red-eye flash photography Increasing textile kiss coat operation speed	Ellen Domb Darrell Mann Frank Gace, et al.	July 1997 July 2001 Jan 2001
P S	Physical contradictions Separation principles	Particle filled fibres Fire-proof staircases for high-rise buildings Innovation & current business stewardship	Stan Bachelor, et al. Toru Nakagawa Jack Hipple	Oct. 1999 April 2001 Aug 1998
P S	SU-field analysis 76 standard solutions	Profitable e-commerce Improving world food supply Increasing speed of yarn spinning	Darrell Mann Joe Miller, et al. Vikram Khona, et al.	April 2001 April 2001 Aug 1998
P S	Function analysis Trimming	A novel heat exchanger Coating process for photographic paper Automatic boarding machine design	Bokuslav Busov, et al. Ian Mitchell Benjamin Kunst, et al.	Dec 1999 Aug 2000 Jan 2000
P S	Maturity curves Trends of evolution	A better wrench Refrigerators & refrigerant compressors Yarn spinning technology	Darrell Mann Darrell Mann Severine Galinde	July 2000 July 1999 July 2000
Key: P= problem or situation analysis tool	S= solution or knowledge-based tool			

Table 6.2: Common combinations of TRIZ tools based on current practice

sequential processes

These processes have been developed to help practitioners tease apart complex problems in a systematic way. Various TRIZ trainers and software developers suggest sequential processes, which can be extensive and complex. The background to some of these processes is described in the last part of section 6.1.2. There are many different 'schools of TRIZ' and consequently, the suggested sequential processes vary (Mann, 2000c; Royzen, 1999; Invention Machine, 1998; Domb, 2000b). The overall structure presented in figure 6.3 summarises what was generic across the processes studied.

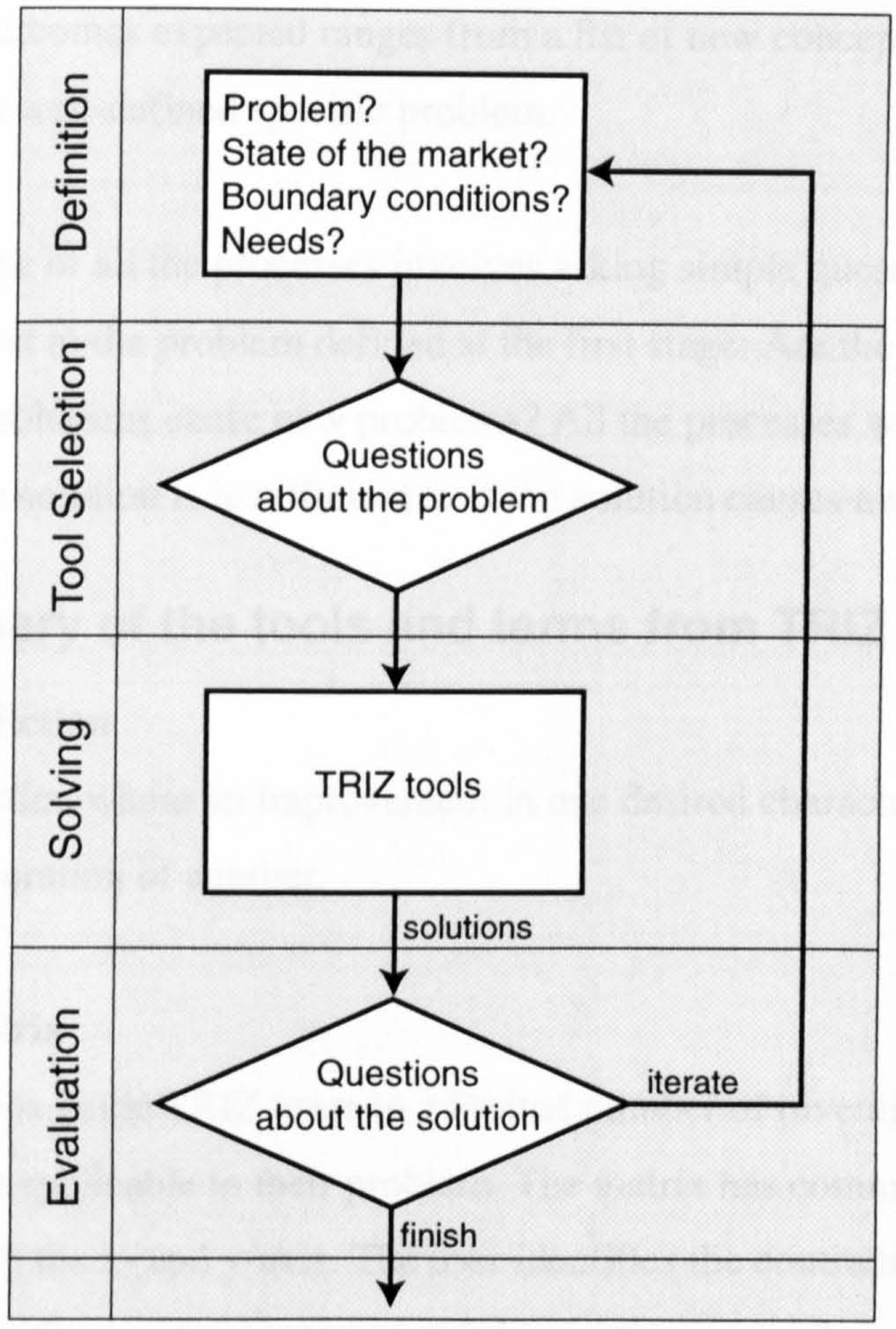


Figure 6.3: Structure summarising what was generic across the processes studied

The range of approaches at the definition stage is diverse, activities may include: formulating the problem; benchmarking the current state of the market; determining the boundary conditions for the projects or identifying needs.

In the processes reviewed, the selection of TRIZ tools is based on the type of problem defined at the definition stage. Flow charts often use a series of questions to guide the user to the appropriate TRIZ tools. These flow charts vary a lot, examples of questions asked might be: Does the cause need revealing? Is it a detection or a measurement? Is it a conflict? Is it a harmful action? Absent or insufficient action? Is it a useful action? Super-system or sub-system change? Forecasting potential for changes?

It is difficult to identify common practice at the solving stage due to the number of different tools within the TRIZ toolbox and their individual adaptation by practitioners.

The spectrum of outcomes expected ranges from a list of new concepts, through to a single solution to a well-defined specific problem.

The evaluation stage of all the processes involves asking simple questions about the solution with respect to the problem defined at the first stage: Are the solutions sufficient? Do the solutions cause new problems? All the processes will iterate back to the first stage if the solution is insufficient or if the solution causes a secondary problem.

6.1.2 Glossary of the tools and terms from TRIZ

Technical contradiction

A type of contradiction where an improvement in one desired characteristic of a system results in the deterioration of another.

Contradiction matrix

A matrix which helps guide TRIZ users to a limited number of inventive principles, which may be most applicable to their problem. The matrix has common contradicting attributes along both the x- and y-axis. The user identifies the contradicting attributes of his system and finds three or four recommended inventive principles at that intersection point in the matrix.

40 inventive principles

The fundamental principles identified by Altshuller (Salamatov, 1999) which recurred whilst studying successful inventive practices. The principles represent common ways of resolving contradictions in systems and thereby overcome the 'design by compromise' paradigm.

Physical contradiction

A type of contradiction where an *element* of a system is subject to opposing requirements.

Separation principles

These are generic problem solving principles used to overcome physical contradictions. The separation principles vary from three to five according to different authors. The most commonly accepted principles are separations: in space, in time, and between a whole system and its parts.

SU-field analysis

SU-field from TRIZ - also referred to as S-fields theory - is another system for classifying the problem to be solved. It is a minimal model of a functioning system. The system consists of a minimum of two substances with a field acting upon them. Examples of *fields* are: mechanical, thermal, and chemical. The interactions between the two *substances* might be effective, insufficient, excessive or harmful in a problematic situation.

76 standard solutions

The 76 standard solutions are used to transform an incomplete or inadequate SU-field. The standard solutions are organised into five classes with several sub-groups to help guide the user to the most relevant standards. The SU-field analysis identifies which class of standard solutions are appropriate for that problem. The five classes are: build or destroy an S-field; develop an S-field; transition to the super-system or to the micro level; measure or detect within the system; and introduce substances or fields into the system.

Functional analysis

Functional analysis is another way to classify the problem to be solved. Other forms of functional analysis have been developed outside TRIZ. In functional analysis a diagram is drawn of the system to be considered for invention. The main useful function (MUF) and components of the system are defined and both positive and negative inter-relationships between components are identified. Functional analysis creates clear generic relationships between the elements and allows users to seek solutions from disciplines other than their own.

Trimming

A tool often used if functional analysis has highlighted obvious components that can be eliminated whilst maintaining the main useful function (MUF). Trimming is widely used by engineers and has much in common with established engineering design approaches such as DFMA - design for manufacture and assembly. Trimming is also one of the recognised technology evolution trends.

Technology maturity curves

Although TRIZ provides an understanding of the patterns of evolution for technical systems, no specific technology maturity tools were contained in classical TRIZ. In recent years TRIZ users have developed ways to determine the type of problem that is to be solved and evaluate the market conditions for the product or system. Technology maturity curves have been used to create innovation strategies. S-curves are not directly associated with classical TRIZ but are often used by practitioners.

Trends of evolution

Classical TRIZ describes eight generic patterns of evolution for technical systems, such as: dynamization, transition to a bi- or poly-system, synchronisation, and scaling up or down. The 76 standard solutions were based on these discoveries, however in recent times the trends of evolution are used as solution tools in their own right. The trends of evolution create innovation strategies and help users commit to step-changes for their product or system. The eight generic trends have been expanded and illustrated by different TRIZ developers to create accessible idea-generating tools (Invention Machine, 1995; Ideation International, 1998; Creax, 2002).

Physical, chemical and geometrical effects

This knowledge-based tool was one of the last to be developed in classical TRIZ and tends to be used when all other tools have failed to solve a problem. The tool is based on the discovery that radical technical solutions often resulted from the new application of a fundamental effect from physics. The 'pointers to effects' were collated, with descriptions of effects and examples of their uses (Altshuller, 1984). These 'pointers to effects' create a bridge between engineering and pure physics, chemistry and geometry.

Multi-screen advanced thinking (9-boxes)

The multi-screen or 9-box diagram falls into the category of tools to overcome mental inertia, because it is mostly used to predict or imagine a future system. The practitioner fills in the boxes in the diagram - shown in figure 6.4 - to describe the system to be designed.

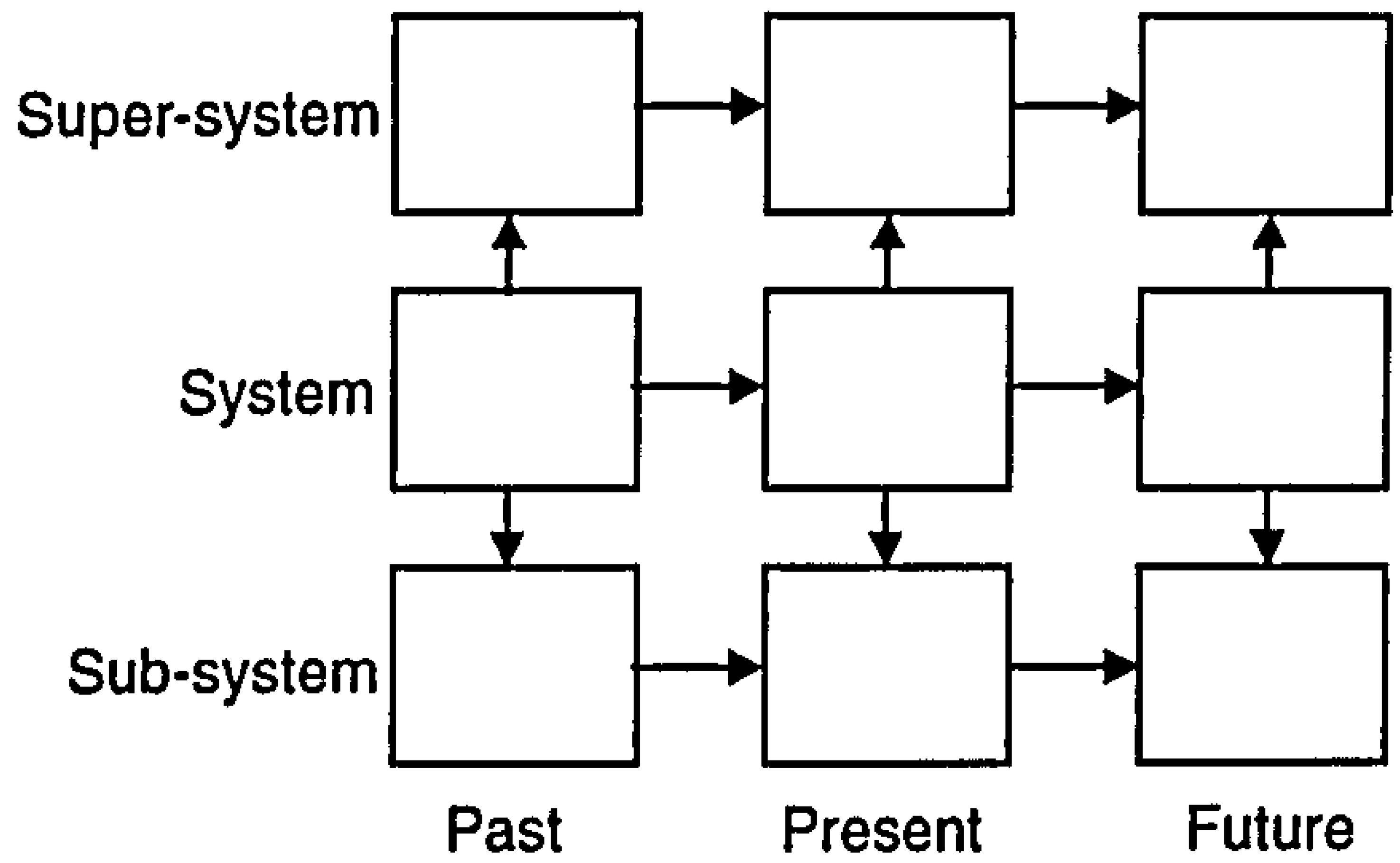


Figure 6.4: Multi-screen diagram

Again, the multi-screen diagram helps users to define innovation strategies and commit to step changes for their product or system.

Ideal Final Result (IFR) statements

IFR statements are the useful embodiment of TRIZ's ideality theory. The user is asked to eliminate the constraints of today's solution and to envision the 'ideal final result' situation, where the function is performed without any resources, cost or harm. The mental inertia of the designer is overcome by conducting this mental leap forward. Subsequently, the user works 'backwards' towards more appropriate solutions. The process defines the steps required to work towards the Ideal Final Result. This method is known outside TRIZ as 'back-casting': a technique used in design workshops.

Smart little people modelling

Another tool to overcome mental inertia is 'using smart little people' which was originally called 'modelling with miniature dwarfs'. This tool specifically helps the user to understand problems and conflicts at the micro-level. The user must sketch the problematic parts and use a 'crowd' of small people in the system as workers. Prescribing their actions and conditions may provide ideas for fundamentally new relationships at the micro-level. Figure 6.5 shows a moving part from the investigation of a yarn spinning system where the little people represent the conflict between the ring and the traveller (Khona, Slocum & Clapp, 1999).

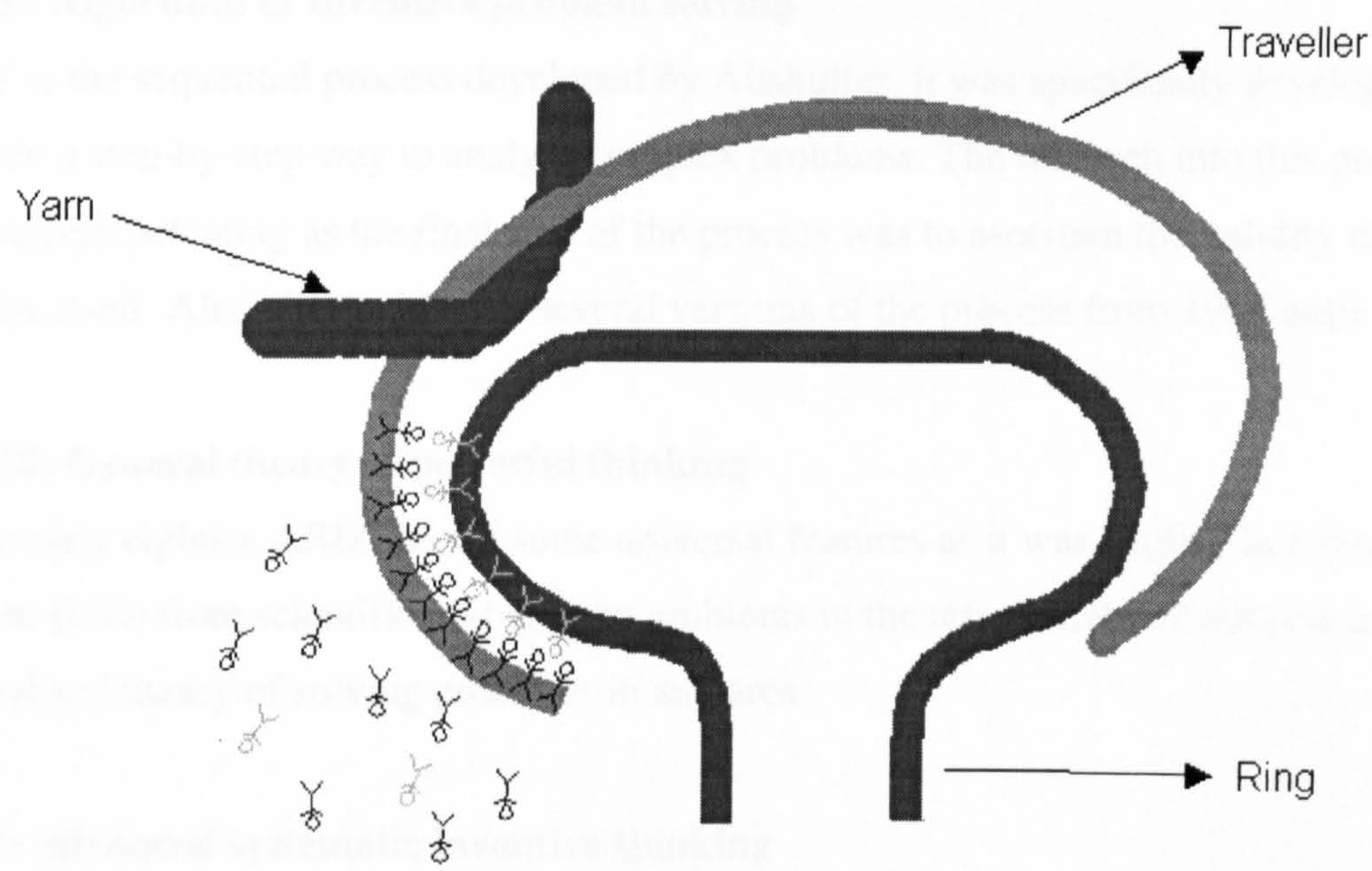


Figure 6.5: Smart little people model of a problematic spinning head (Khona, Slocum & Clapp, 1999)

Size-Time-Cost Operator

One of the early tools to overcome mental inertia developed from classical TRIZ is the Size-Time-Cost (STC) operator. This investigative exercise involves six mental operations: Increase the size of the object to infinity, then reduce it to zero, repeat for both time - rate of movement for example - and allowable costs associated. This tool is little used in current practice.

Strategy of forming a Creative personality (TRTL)

In the late 80's Altshuller discovered that although acceptance of TRIZ was increasing in certain engineering disciplines, there were low numbers of life-long users and a disappointing take-up of the fundamental principles in other disciplines. Altshuller decided to investigate TRIZ users and identify patterns in 'the formation of a creative personality' that could be utilized to increase the effectiveness of TRIZ education. He identified the qualities prevalent in life-long users. This led to the Lifetime Strategy for a Creative Individual (LSCI) and Theory of Building a Creative Personality (TBCP). Although these theories are not often discussed, the future of TRIZ dissemination and TRIZ education is an important topic in recent conferences and seminars.

ARIZ: Algorithm of Inventive problem solving

ARIZ is the sequential process developed by Altshuller. It was specifically developed to provide a step-by-step way to analyse complex problems. The research into this process was self-perpetuating as the final step of the process was to ascertain the validity of the process itself. Altshuller published several versions of the process from 1968 until 1985.

OTSM: General theory of powerful thinking

In the early eighties ARIZ gained some universal features as it was applied in a range of diverse fields from scientific problems to problems in the arts. OTSM developed as a generalised theory of solving problems in any area.

ASIT: advanced systematic inventive thinking

Many TRIZ trainers have developed some kind of simplified process to help train novices in TRIZ. The first recorded version was perhaps Systematic Inventive Thinking (SIT) by Filkovsky (Horowitz, 2001). ASIT is a simplified TRIZ process based on SIT, which aims to offer industry a simple, effective way to teach, learn and apply TRIZ methods. It was developed in the 80's by Horowitz.

USIT: Unified Structured Inventive Thinking

USIT is a simplified TRIZ process developed in 1995 by Ed Sickafus at the Ford Motor Company (Nakagawa, 2001a). USIT aims to offer a clear and simplified procedure for solving problems using TRIZ. USIT can be represented by a 6-step flowchart.

6.2 TRIZ tools in current industrial practice

The overview of TRIZ tools, fundamental discoveries, and processes has created a better idea of the diversity of TRIZ. This diversity of tools and methods is also acknowledged as one of the barriers to its adoption in industry. Potential users can be overwhelmed by the number of tools and processes when first encountering TRIZ (Mann, 2002).

This section presents a summary of published work by TRIZ consultants experienced in introducing a variety of TRIZ tools and processes in industry. The barriers to take up of TRIZ in industry are explored and the more successful tools and approaches are discussed.

6.2.1 Barriers to take up of TRIZ in industry

In general designers - problem solvers - in industry lack the time to take up new methods and to spend time learning to use and integrate new tools.

Hipple (2000) identifies two main barriers to the take-up of TRIZ in industry. Firstly, the competition that TRIZ has with other creativity and problem-solving tools already established in companies; existing tools normally have a track record of success in the company and using new tools requires a considerable time investment. Secondly, there are a number of human factors that affect the take-up of TRIZ; parts of the theory may go against the instincts and experiences of established designers and engineers. For example, experienced designers may have come across many un-resolvable difficulties in their career, this means that they may object to the concept of 'ideality'. Also, designers' reputations can be at stake; resolving contradictions often makes obsolete complicated designs that much time has previously been invested in. Solutions from TRIZ are sometimes 'sabotaged' by the owners of existing solutions.

6.2.2 Most popular and flexible tools

TRIZ's richness and diversity has been identified as both a benefit and a problem. It is therefore valuable to establish which aspects of TRIZ are most flexible and easy to integrate into existing design practice. Mann (2002) explains how several tools from TRIZ can be learned in a relatively short time, whereas the fundamental discoveries may take a lot longer to appreciate and the processes are often overwhelming.

It was stated at the start of this chapter, that the number of core tools employed in TRIZ practice today is only about twelve (Mann, 2002). The popularity and the final take-up of a tool will be greater with successful examples of implementation as part of its introduction. Examples of tools with high take-up are: the contradiction matrix, trends of evolution and some of the inventive principles.

6.2.3 Advice for the successful integration of TRIZ into industry

Mann (2002) has described four different ways in which people take up TRIZ. He states that it is not possible to determine the most useful parts of TRIZ as this depends on the circumstances, the user and how TRIZ is taught. It is important to encourage users to adapt TRIZ to their existing way of working. Hipple (2000) also stresses that it is better to introduce TRIZ into an existing innovation program and that different teaching approaches are needed for different types of user. He recommends identifying 'eager learners' and working with early technology adopters.

In some situations there may not be a need for tools to generate new ideas, in which case the emphasis is best placed on the situation or problem analysis parts of TRIZ. When new to TRIZ designers often prefer the problem *solving* tools even though the problem *definition* tools are some of the most important and valuable.

6.3 The TRIZ perspective on environmental design

Having given a general introduction to TRIZ the rest of this chapter explores TRIZ in relation to environmental design research.

6.3.1 TRIZ originators work on sustainable technology development

In the 80's the originators of TRIZ began research on technology evolution and its effects on nature. In 1983, Altshuller set out to develop a new direction for TRIZ which would allow technology to develop intensely whilst at the same time preserving nature. Today, this would probably be called sustainable technology development.

However, after some time he concluded that there would be no turning back from the 'fulfilment of desires using the currency of nature': a fundamentally destructive trend. In 1991, he presented his findings in a controversial paper and at various seminars (Altshuller & Rubin, 1999).

His analysis starts with a strong statement that 'nature is doomed', and the belief that even with careful preservation, nature will be dislodged by technology. This destruction of nature will mean that the 'basic gifts' of nature - oxygen, water, food - will have to be provided artificially. He makes some calculations based on existing technologies able to artificially provide those functions, assuming that the world population would stabilise at 8 billion around year 2080 and that the power of all energy systems at that time will be 7×10^{10} kwt. He concludes that it would be possible to provide oxygen, water, and food. He sketches out eight thoughts about technology and nature and presents a model for a Nature-less Technological World (NTW).

This work caused uproar in the TRIZ research community. Many critics strongly questioned Altshuller's NTW theory, objecting to the fundamental concept of a 'world without nature'. The work did spark off more development within TRIZ of future forecasting methodologies: a strong focus, which continues to this day. However, sustainable technology development was not noticeably taken up within the TRIZ research community; the research summarised in section 6.4, has all been undertaken by researchers outside the TRIZ community.

6.3.2 Fundamental TRIZ discoveries showing good fit with the aims of eco-innovation

This section looks at some of the core principles of classical TRIZ which inherently overlap with principles from eco-innovation.

Contradictions

TRIZ states that inventive solutions eliminate trade-offs rather than accepting them, and that there is a defined set of inventive strategies to help eliminate such trade-offs. This is relevant to environmental design because designers generally believe that to improve reliability, quality, sustainability or any other aspect of a design inherently means that some other aspect of the design must get worse. Lawson (1990) says that design is normally seen as a problem-solving activity in which: it may not be possible to state the problem comprehensively in the first instance; optimal solutions might not exist; and problem-solving activities revolve around *compromise*. Contrary to this model, TRIZ seeks to utilise the knowledge that designers - including those from other fields - have built up, where the contradictions between the opposing aspects of a design *have* been successfully eliminated.

Ideality and the evolution of systems

One fundamental concept of TRIZ is that all systems will evolve towards an increased degree of ideality; an ideal system is one that delivers its required function, without cost or harm (Salamatov, 1999). Innovation following this principle of 'ideality' could contribute to sustainable development, through the delivery of useful functions to consumers without the environmental impacts associated over the product's life-cycle.

Ideality can be expressed as a qualitative equation of benefits divided by the sum of costs and harms, where 'harm' can specifically include environmental impacts. Ideality can drive the design towards an 'ideal final result' - a design that is the best that can be envisaged.

$$Ideality = \frac{benefits}{(costs + harms)}$$

Use of resources

TRIZ states that the strongest solutions turn 'bad' elements of a system into useful resources. The TRIZ definition of a resource is 'anything in or around a system which is not being used to its' maximum potential'. This means that elements normally viewed as harmful - such as waste - are also treated as resources awaiting a designed use within the system. Embracing this view of resources could help drive environmental improvements at the system level.

6.4 Review of research on TRIZ for environmental design

Although the use of TRIZ in environmental design has been limited to date, awareness of the methodology is slowly growing. This section summarises research conducted by three authors in this field and initial insights offered.

Stevenson has conducted research on sustainable product and process design and TRIZ (Stevenson, Kogan & Kinnel, 1999). Having reviewed existing methodologies in sustainable design, she concludes that a systematic approach to sustainable design is greatly needed. Having worked closely with TRIZ experts in an innovation consultancy, Stevenson believes that TRIZ methods can offer the sophistication required for eco-innovation. She also identifies the need to solve environmental design problems at the higher system levels.

Low, et al. (2000) have explored the use of TRIZ to assist in the generation of innovative environmentally friendly solutions. Their paper looks specifically at one environmental design strategy: product-to-service eco-innovation, where products may be substituted by services to fulfil the consumers' needs whilst decreasing the amount of material consumed. They also support calls for environmental design at higher system levels by identifying the need for 'macro models' of new solutions' impacts. They tried a limited set of TRIZ tools - separation principles and contradiction matrix - and found that they were best suited to product-centred solutions and had limited ability to address problems within a 'multi-hierarchical system'.

In his doctorial thesis, Lamvik (2001) also focuses on product to service eco-innovation. He looks specifically at the separation principles from TRIZ to overcome the physical contradictions identified in the structure of the product system: the side effects of a product's design, manufacture and delivery. The separation principles - structure, space and time - contribute to his final strategy for product to service eco-innovation.

All three contributions explore parts of TRIZ, but none provides a broad review of the different TRIZ tools. Neither do they provide an overview of a process for applying the

TRIZ tools in eco-innovation. They agree that approaches in sustainable design or eco-innovation must focus on solving problems at the higher system levels.

6.5 Comparing two tools from TRIZ and Eco-Innovation

This section looks briefly at the overlap between one eco-innovation tool and one TRIZ tool - the eco-compass and the contradiction matrix – to provide the first ideas for adapting TRIZ for eco-innovation. The eco-compass (Fussler & James, 1996) and its intended use have been explained in section 3.3 under 'starting points'.

TRIZ parameters compared to Eco-compass headings

This study compared the axes of the contradiction matrix and the headings on the eco-compass axes: the 'engineering parameters' from TRIZ were compared with the 'environmental parameters' defined by the eco-compass.

This revealed considerable overlap between the engineering parameters and several of the headings on the eco-compass axes (See figure 6.6). This study also showed that some eco-innovation strategies – reducing health and environmental risk, revalorisation of wastes and resource conservation - are only blanket covered under the engineering parameter 'harmful side effects'.

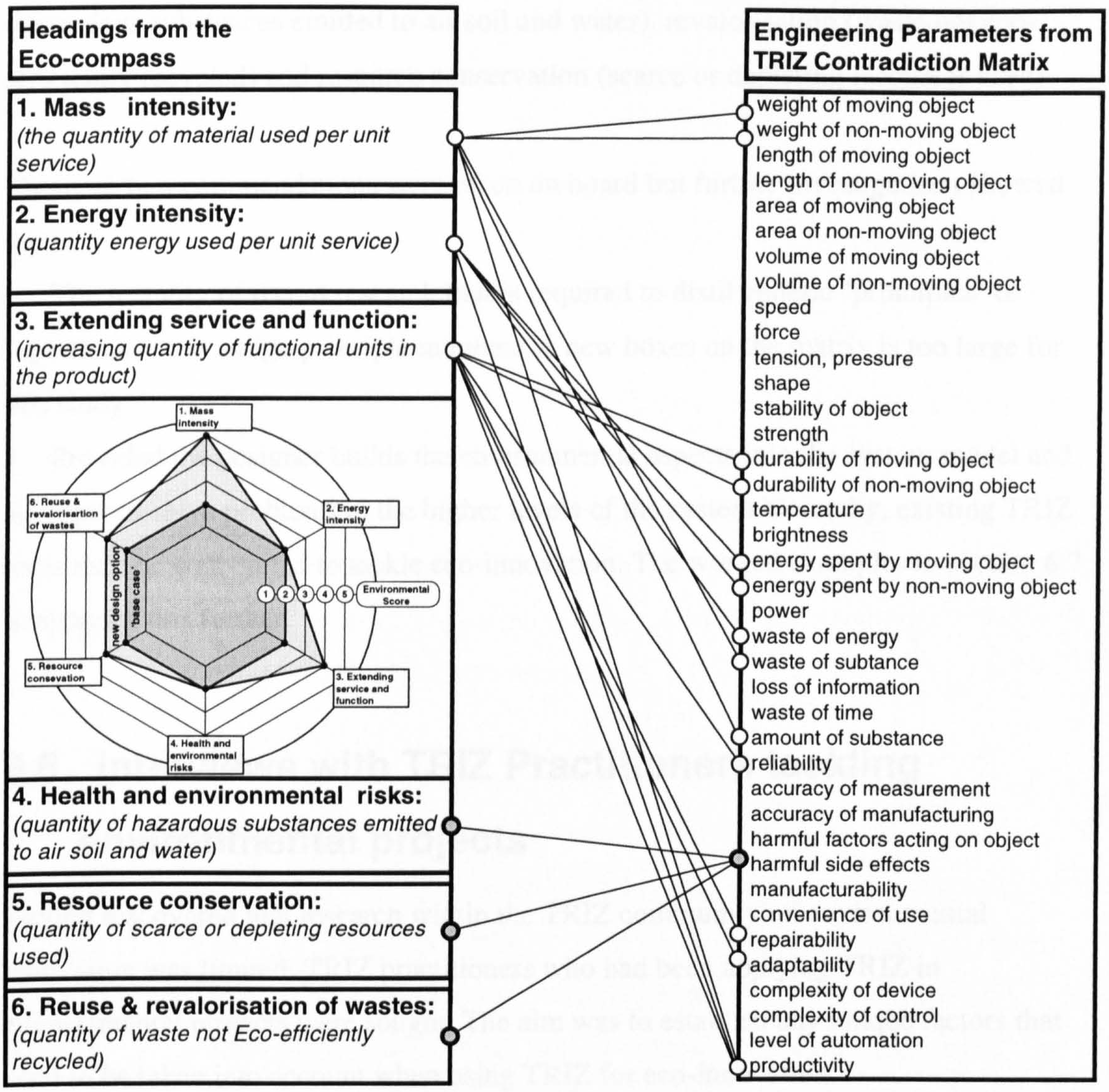


Figure 6.6: Comparing eco-compass headings and TRIZ parameters

This early study identified two ways in which TRIZ might be *adapted* for use in eco-innovation (Jones & Harrison, 2000):

- By studying many more patents of innovative, environmentally designed products it might be possible to extract some generic ‘principles’ or ‘operators’ for solving environmental contradictions. Environmental contradictions tend to be present at the higher system levels, therefore ‘operators’ for eco-innovation should support strategic environmental product management.
- From studying the ‘engineering parameters’ of the contradiction matrix it would be useful to develop TRIZ to cover more explicitly: health and environmental risk

(hazardous substances emitted to air soil and water), revalorisation (waste not eco-efficiently recycled) and resource conservation (scarce or depleting resources used).

These early recommendations were taken on board but further investigations showed that:

- The quantity of patent research that is required to distil generic 'principles' or 'operators' or to assign principle numbers to new boxes on the matrix is too large for this study.
- Provided the designer builds the environmental aspects into the system model and attempts to solve problems at the higher levels of the system hierarchy, existing TRIZ tools may be well-suited to tackle eco-innovation. The worked examples in section 6.7 investigate this further.

6.6 Interviews with TRIZ Practitioners tackling environmental projects

Having discovered that research within the TRIZ community on environmental innovation was limited, TRIZ practitioners who had been applying TRIZ in environmental projects were sought. The aim was to establish any unique factors that need to be taken into account when using TRIZ for eco-innovation.

To increase the possibility of finding experienced TRIZ practitioners to interview, the selection criteria for projects were softened from 'eco-innovation projects' to 'projects which had an environmental angle'. These telephone interviews were arranged in advance and consent was given to record them. In total three individuals and one group were interviewed.

These interviews were semi-structured: a range of questions and topics to be addressed were predefined but the methodology was flexible enough to allow the respondent to initiate new topics or expand on relevant issues (Payne, 1999). The open questions elicited longer narrative responses whilst closed questions were used to check factual responses. Appendix 3 is one of the interview transcripts; the questions prepared are in bold text. When the interview recordings were transcribed, the respondents' remarks were organised under these questions; the transcripts are therefore not chronological.

The projects discussed in the interviews were:

Project 1. A new type of generator, which uses a high temperature fuel-cell and a proprietary heat engine technology to provide homes and commercial buildings with heating, cooling, electricity and hot-water.

Project 2. An improved diesel engine which was made cheaper and emission-compliant.

Project 3. A new system which combines an anaerobic sewage digester with a combined heat-power generator and accelerated composter, to supply a community with electricity, heating and compost.

Project 4. An improved coating process involved in producing photographic paper, which reduced running costs and maintenance.

The project set-up, scope and organisation varied across the four projects and these factors are summarised in table 6.3. The two industry based projects (2 and 4) have resulted in implemented changes with immediate benefits, which were carried out within a year of their start. The two projects that involved the development of new system concepts (1 and 3) have both resulted in worked paper designs that are at the pre-prototype stage awaiting further funding. These new system concepts have been developed over 2-3 year time spans. The interviewees were asked about the drivers of their projects. All described environmental and business drivers. In all four projects the environmental drivers were linked directly or indirectly to existing or impending legislation.

	Project 1	Project 2	Project 3	Project 4
Project Set-up	A subsidiary company has been set up within a TRIZ consultancy to develop and commercialize the new product concept.	The TRIZ practitioner in this case was employed by a manufacturing company for a year to work on process improvement in general.	The TRIZ practitioner met an entrepreneur at a conference on alternative technology and has been collaborating since. The new product system was developed from a business opportunity identified by the entrepreneur.	The TRIZ practitioner in this case runs a 'TRIZ group' (of about 6 members) within his company to practise TRIZ and tackle innovative projects.
Project scope	The project aims to develop an innovative, but market-ready product. The product's technologies will be developed to a stage where the product can be commercialized.	One of the projects tackled involved improving an existing product within that manufacturing environment to ensure that the product could be launched in a new market.	The project aims to develop a new product system which would provide a sustainable and/or profitable opportunity for entrepreneurs, supermarkets, water companies and/or housing communities.	This project is part of a general efficiency drive to reduce the energy consumption of their manufacturing process. The solution was beneficial and could be implemented directly.
Project organisation	The core team consists of 10 main members, they pool outside experts from particular science and technology fields.	There was an internal team of people but the TRIZ practitioner developed the solution alone.	The TRIZ practitioner has investigated the technologies involved and developed the new product system design. The entrepreneur has begun building a prototype.	The group worked on the initial problem. Two members then carried out detailed investigations. The group got together to generate solutions which were later tested and implemented.
Business drivers	To increase the return on investment by developing and commercializing the product based on intellectual property built up within the consultancy.	the product's overall performance was not competitive in the market and needed to be improved.	the entrepreneur originally conceived a commercial opportunity to make compost from supermarket waste.	Bringing energy consumption down offers significant cost saving opportunities, as their product is extremely energy intensive to manufacture.
Env. drivers	In general, society is slowly driving legislation and business towards more sustainable practices and products.	Current US emission targets meant that their product could not be marketed in the US. The company needed to break into the US market.	The composting aspect of the project is driven by EU guidelines for reduction of land filled waste, which directly affects community waste programs.	Indirectly, this project was driven by the impending threat of the Climate Change Levy which puts a significant financial burden on this producer because his manufacture process is so energy intensive.

Table 6.3: Summary of four projects with an 'environmental angle': the set-up, scope, organisation, business drivers and environmental drivers of the projects

The interviewees were asked about their general practices when employing the TRIZ tools. They were asked about: their process; which tools were used; the employment of those tools; and the iterations conducted. Three of the four groups followed some pre-described process through their projects (1, 3 and 4). However, the more experienced practitioners (projects 1 and 3) used the TRIZ toolbox and their process as a roadmap: flexibly, at different levels of the system and making longer stops when necessary. The less experienced group (project 4) used one of the TRIZ software tools to guide them through this project carried out a few years ago. They followed the prescribed process closely. Subsequently, they have successfully completed several other projects and have developed their own process using TRIZ tools and find themselves using the software less. The experienced practitioner working alone (project 2) followed no systematic process and applied the TRIZ tools in an instinctual way. When working in teams it may be valuable to have a systematic process to help different team members to follow and contribute to the innovation process. Groups 1, 3 and 4 all reported iterating through their process as new problems emerged, their projects involved working through different levels of the system hierarchy.

These interviews were aimed at establishing whether there were any factors that needed to be taken into account when using TRIZ for eco-innovation. All agreed that there is no special adaptation of the TRIZ toolbox needed to employ it in projects with an environmental angle. Some comments were made highlighting the merits and limitations of using TRIZ in the environmental arena; these are summarised in table 6.4.

Project 1
TRIZ is particularly powerful because it is a functional approach applicable at high or low levels of the system hierarchy and enables the user to draw on solutions from across industries. TRIZ looks at super-systems, systems and sub-systems and the connections to the super-system could be environmental legislative drivers. TRIZ does not look only at reducing inputs and outputs but looks at using all resources in the system including waste. TRIZ is a versatile set of tools, with a proven track record in problem solving that existing environmental design tools lack.
Project 2
Using TRIZ to optimise the system reduces the burden on the eco-system, however, environmental impact is closely linked to the way society applies new technology. This often falls outside the remit of a technical TRIZ project.
Project 3
Using TRIZ in environmental projects has shown that the most beneficial projects often require some systems change. Factors hindering the take-up of such system inventions are: • Resistance to diversification in industries involved. • Resistance to establishing new combined systems in industries previously unconnected. • Government and industry lack the commitment to invest in radical environmental systems at the scale required to achieve greatest efficiency.
Project 4
Environmental issues can be included in the TRIZ project when using functional analysis, by adding the environment (air, water, etc) as components that interact with the system.

Table 6.4: Comments on using TRIZ in the environmental arena

The main conclusion is that TRIZ's existing problem solving tools can be used for environmental projects. However, what finally determines its ability to improve eco-innovation are the definitions of the scope or the frame of the projects. Firstly, the definitions at the super-system level must at least include recognition of the environmental issues or drivers. Secondly, fundamental questioning of the function and/or needs that the product is going to fulfil is necessary in order to achieve the most environmentally beneficial results. These interviews also highlighted that it may help to have a systematic process for applying TRIZ tools in team design practice.

6.7 Worked examples using selected TRIZ tools for environmental improvement

The previous sections have established that environmental aspects need to be built into the systems model and problems need to be tackled at the system level. This section investigates the ability of a selection of TRIZ tools to contribute to eco-innovation practice. Worked examples have been created and the type of ideas outcome from them is examined.

In two of the three case studies described below an external TRIZ expert used tools from TRIZ to generate ideas, whilst the preparation of the background to the cases and analysis of the ideas outcome was conducted by this author. The tools were selected by the TRIZ expert from the popular or commonly used TRIZ tools. The TRIZ expert worked in his established way and was not specifically briefed to work at the system level. This meant that 'normal use' of the tools could be assessed with regard to its ability to contribute to eco-innovation.

The three studies are each described in depth in the following publications: Jones, & Harrison (2000), Jones et al. (2001) and Mann & Jones (2001). This section puts together the three studies in a consistent format. The second and third study allow some conclusions to be drawn on the ideas outcome from the TRIZ tools used. An evaluation table at the end of those studies looks at the idea outcome from each tool in relation to the criteria distilled from this chapter and chapters 4 and 5. Figure 6.7 shows an example of the evaluation table used and the criteria established are described below:

Original and appropriate

Tools for eco-innovation should generate both original *and* appropriate solutions that have the potential to be taken up in industry. Therefore the outcomes from the studies will be marked *original* if the solution is not seen in common current designs. The outcomes will be marked *appropriate* if they could be taken up in existing industry.

System levels

The tools must support design at the different system levels and further promote solving problems at the higher system levels. The outcomes from the studies are placed in relation to a system hierarchy. Each outcome will be marked as either a solution at the sub-system, system or super-system level. These levels are defined separately for each of the three studies.

Incremental or radical

The tools must support step-change design. Solutions at the higher system level will tend to be the more radical - or step-change – ideas. This evaluation criterion confirms the link between the system-level and the step-change of the solution. Each outcome will be marked on a seven-point scale between at one end *incremental* and at the other *radical.* A similar scale was used by Sherwin (2000) as a framework to summarise parts of his literature review. The outcomes judged incremental are those that are small improvements to existing products or the redesign of existing products. The outcomes judged radical are those that represent a step-change in the way the function is fulfilled.

Environmentally relevant

Although the worked examples are set up as eco-innovation case studies it is worth cross checking the environmental relevance of the outcomes from the use of the tools. For this criterion the ideas are marked as environmentally relevant when they show potential to reduce the environmental impact of the product or system throughout its life cycle with or without possible rebound effects.

tool used:	idea summary:	original: not seen in current versions	approriate: could be taken up in existing industry	sub-system: new elements/parts of an existing dishwashing device	system: a new type of dishwashing device	super-system: a different way of domestic dishwashing	incremental: small improvement or redesign of existing dishwasher						radical: a step-change in the way the dishwashing function is fulfilled	environmentally relevant: shows potential to reduce the environmental impact of dishwashing

Figure 6.7: Evaluation table containing the criteria established

The first study is an explorative study in which TRIZ tools are not applied directly. Instead, the evolution of an innovative environmentally designed product and its patent are studied and inventive principles from TRIZ evident are highlighted. The second and third studies are more conventional; the background to the cases is collated and subsequently the TRIZ expert applies the tools. Section 6.7.4 summarises the outcomes from the three studies.

6.7.1 Fluorescent tube lighting study

This started with the search for an 'eco-innovation exemplar' to study. The subject chosen was energy-efficient lighting. First, the development of energy efficient lighting was studied to select the most relevant products and a limited time span over which to study their patents.

The author wanted to select the most relevant product in energy efficient lighting and immediately thought of the compact fluorescent lamp (CFL). CFLs use a quarter of the amount of energy for the same unit function as a standard incandescent light bulb and have a service life at least 10 times longer.

However, from studying the development of lamp technologies many environmentally relevant innovations were found in ordinary fluorescent tube lamps. A map summarising the evolution of lighting technologies can be found in figure 6.8. CFLs were often secondary adopters of technologies such as the improved phosphors and high frequency dimmable ballasts. For these reasons conventional fluorescent tube lighting was chosen as the product for the rest of this study. The technology study also showed the period from 1970 to 2000 as a period rich in interesting innovations for fluorescent lamps; a search was made for patents on fluorescent tube lighting from this period.

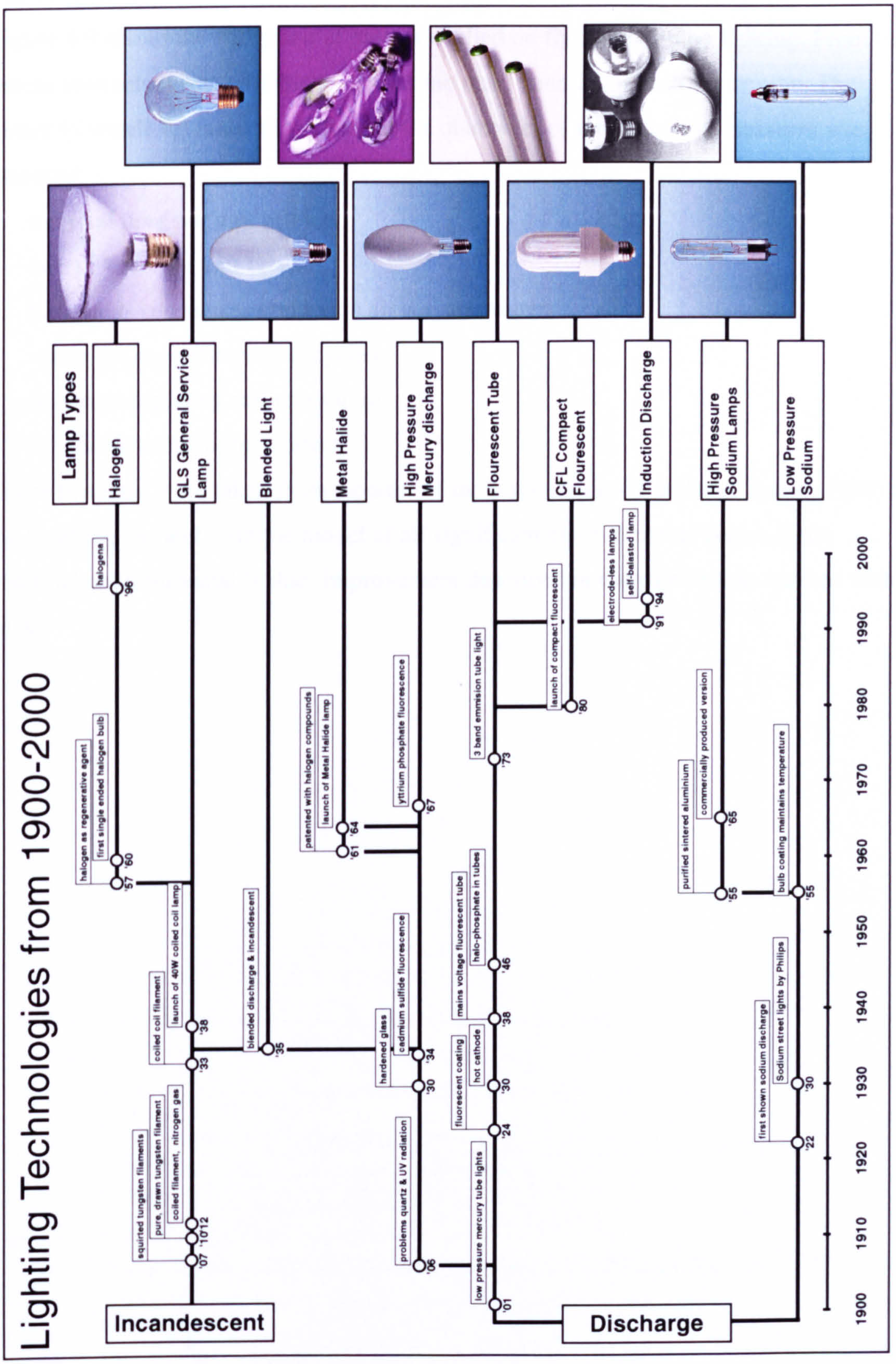


Figure 6.8: Map summarising the evolution of lighting technologies

6.7.1.1 Analysis conducted

Patent overview

Figure 6.9 shows the collection of patents studied on fluorescent tube lighting. From the patent abstracts it was possible to deduce the main benefits of each innovation. The extent to which the innovation changes the quantities of the following measures was assessed:

- material used per unit service;
- energy used per unit service;
- hazardous substances emitted to air soil and water;
- waste not eco-efficiently recycled;
- scarce or depleting resources used;
- functional units in the product.

These headings were taken from the axes of the eco-compass (Fussler & James, 1996) as the headings present a simple model of all significant environmental issues. Each potential environmental 'value' improvement described in the patents was marked with an X.

			Eco-innovation headings					
			material used per unit service	energy used per unit service	hazardous substances emitted	waste not Eco-efficiently recycled	scarce ordepleting resources used	functional units in the product
1971-05-25	US3581139	Fluorescent lamp having Titanium Dioxide-containing glass envelope and reduced phosphor weight	X					X
1971-08-31	US3602758	Phosphor blend lamps which reduce the proportions of the costlier phosphors						
1972-12-26	US3707642	Vapor lamp which incorporates a special phosphor coating	X					
1975-05-27	US3886396	Fluorescent lamp with a protective coating						X
1976-02-10	US3937998	Luminescent coating for low-pressure mercury vapour discharge lamp		X				
1976-06-29	US3967153	Fluorescent lamp having electrically conductive coating and a protective coating therefor						
1978-03-14	US4079288	Alumina coatings for mercury vapor lamps			X			
1978-05-09	US4088923	Fluorescent lamp with superimposed luminescent layers						
1978-06-20	US4096088	Method of preparing cerium and terbium activated aluminate phosphors						
1979-04-17	US4150321	Luminescent aluminates and mercury vapor discharge lamp containing the same		X				
1982-12-14	US4363998	Fluorescent lamp processing which improves performance of zinc silicate phosphor used therein		X				
1984-05-08	US4447756	Fluorescent lamp with layer of plural phosphors having different particle sizes	X					
1985-01-08	US4492898	Mercury-free discharge lamp						
1989-08-22	US4858833	Process for recycling fluorescent and television tubes				X		
1990-04-10	US4916359	Gas discharge lamp envelope comprising a barium sulphate protective layer disposed on its inner surface		X				X
1991-12-05	DE4030732	Processing fluorescent lamp scrap - for recycling of glass, mercury phosphor, and metals avoiding waste and pollution			X	X		
1992-03-03	US5092527	Fluorescent tube crusher with particulate separation and recovery			X			
1992-04-21	US5106598	Lamp reclamation process				X		
1992-12-08	US5170095	Low-pressure mercury vapor discharge light source of high wall loadability						X
1993-07-20	US5229687	Mercury vapor discharge lamp containing means for reducing mercury leaching			X			
1993-07-27	US5230140	Process for environmentally safe disposal of used fluorescent lamp potted ballast assemblies with component reclamation			X			
1994-11-01	US5360169	Process and apparatus for the disposal of articles containing metals or metal vapors			X			
1995-02-14	US5388773	Crushed fluorescent tube particulate separation and recovery method and apparatus				X		
1996-09-03	US5552665	Electric lamp having an undercoat for increasing the light output of a luminescent layer		X				
1996-09-10	US5553708	Packaging for shipping spent fluorescent lamps			X	X		
1999-04-06	US5890940	Lamp recycling apparatus and method for doing the same			X			
1999-04-27	US5898265	TCLP compliant fluorescent lamp			X			X
1999-10-13	EP0949016	Method for treating used fluorescent lamps to recover the glass tubes				X		

Figure 6.9: Collection of patents studied on fluorescent tube lighting

From the table shown in figure 6.9 it is possible to observe a shift in innovation focus. Until the mid 80's the patents mainly record:

- The optimisation of the lamp's production; reduction in the mass of materials used (column 1).
- Increasing competitive performance; longer lamp lives are classified under 'increased functional units in the product' (column 6) and increasing energy efficiency (column 2).

From 1985 onwards the patents start to record developments in recycling processes (column 4) and reducing toxicity (column 3). There were no innovations listed that specifically avoid the use of scarce or depleting resources (column 5).

Detailed patent study

Having compiled the patent profile of fluorescent tube lighting, it would be beneficial to get an insight into the type of contradictions solved in environmentally relevant patents. To do this, such patents would need to be studied in more detail. This section reports on a detailed patent study.

The patent chosen from the overview was US5898265: Toxic Characteristic Leaching Procedure (TCLP) compliant fluorescent lamp. The TCLP test is a toxicity test established in 1990 by the EPA to prevent large quantities of heavy metal going to landfill.

The patent records a combination of innovations that led to environmental (TCLP) compliance for a fluorescent tube lamp, and must therefore contain environmentally relevant innovations. The patent describes the reduction of the total mercury content by more than 80% (factor 4) whilst providing a lamp-life and photometric quality comparable to other commercially available fluorescent lamps. These lamps can therefore be safely disposed of in landfill whilst also being 100% recyclable - a more expensive disposal option. Competitors' lamps often use mercury-binding agents that 'cheat' the TCLP test.

Press releases from the patent owners (Philips, 2000) and product brochures of the fluorescent tube lamps 'Alto' and 'TL'D Super 80' supplemented the information contained in the patent. These helped to explain the environmental benefits of the innovations described in the patent.

Problem and solutions hierarchy

From the patent it was clear that the company had made a strategic commitment to develop a lamp that would pass the TCLP test without cheating, whilst producing a lamp that would still be competitive. In real terms this meant that to pass the TCLP test, they would have to reduce the mercury content of standard fluorescent tubes by at least 75% whilst achieving an energy efficient, 20.000 hour lamp life.

From the company's strategic point of view the 'Environmental contradiction' was between remaining competitive in the lighting market and complying with environmental legislation without cheating. Figure 6.10 shows the 'Environmental contradiction' that the company was trying to solve between lamp performance characteristics and harmful materials in lamps.

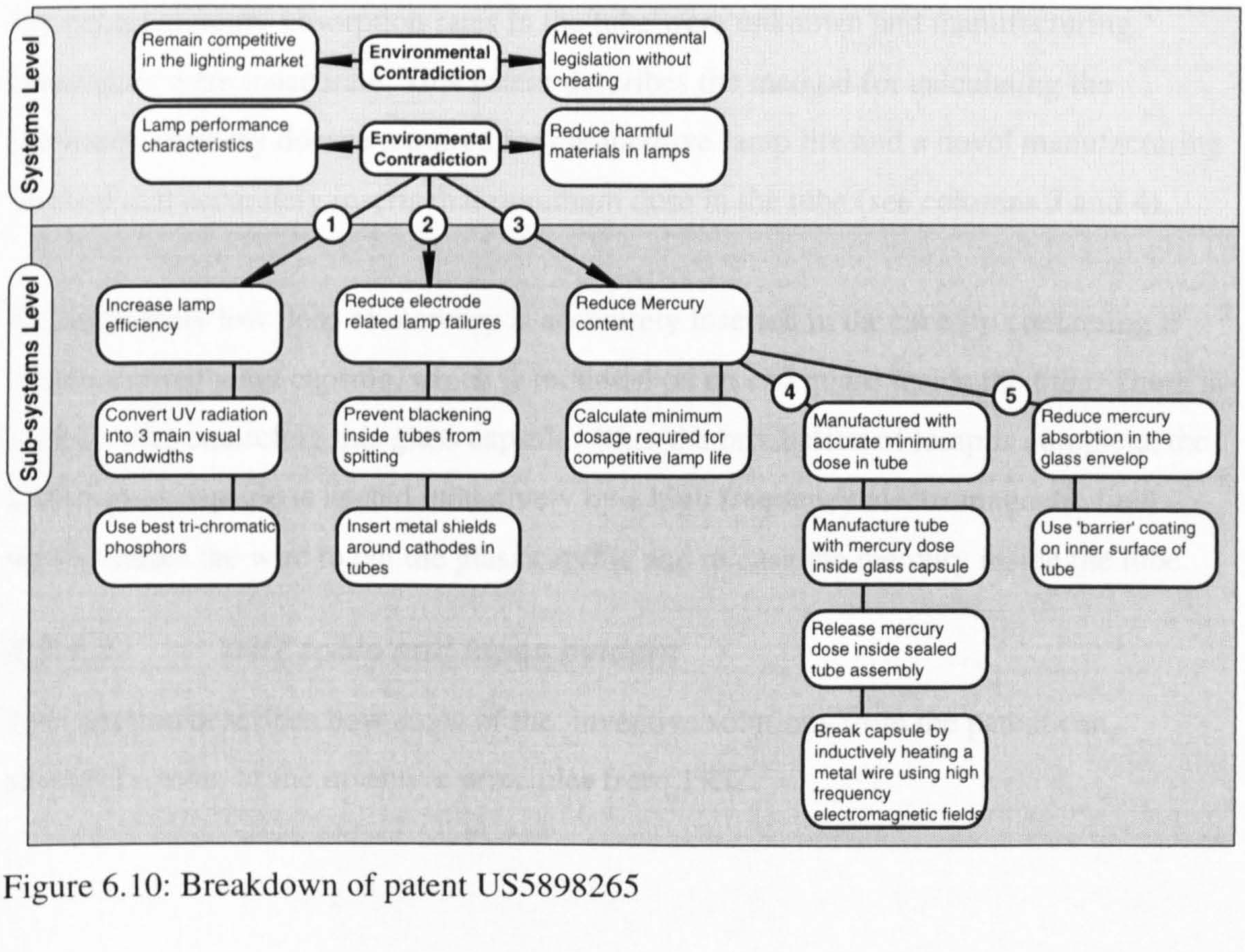


Figure 6.10: Breakdown of patent US5898265

The lamp's lifetime is affected by mercury absorption in the glass envelope over time, electrode failure and tube blackening from spitting electrodes. The lamp's energy consumption is affected by the efficiency of the phosphors to convert the UV radiation into visible light. Figure 6.10 shows the combined approach described in the patent which addresses all these performance factors (see columns 1,2 and 5):

- The best tri-chromatic phosphors are used that efficiently convert the UV radiation into three main bandwidths of visible light, namely, red, green and blue.
- Small metal shields are placed around the cathodes inside the tube to catch the spitting from the cathodes that otherwise causes the tube to blacken and thereby shortens its life.
- Over time the amount of mercury vapour inside the bulb slowly decreases due to its absorption in the phosphor layers and the glass envelope. Special 'barrier' coatings are used to reduce this effect.

The most innovative part of the patent is shown in column 3 and 4 of figure 6.10. Traditionally lamps have always been overdosed with mercury. This was done because the *actual* mercury absorption rates in the tube were unknown and manufacturing techniques were inaccurate. This patent describes the method for calculating the minimum mercury dosage required for competitive lamp life and a novel manufacturing method that accurately inserts that minimum dose in the tube (see columns 3 and 4).

The extremely low dose of mercury is accurately inserted in the tube by containing it within a small glass capsule, which is mounted on an end guard inside the tube. There is a metal wire encircling this glass capsule. After the production of lamp is complete, the sealed glass capsule is heated inductively by a high frequency electromagnetic field which causes the wire to cut the glass capsule and release the mercury inside the tube.

6.7.1.2 TRIZ tools and ideas evident

This section describes how some of the inventive solutions from the patent can exemplify some of the inventive principles from TRIZ.

Technical contradictions

From studying the abstract of the patent, the innovation could be defined as the solution to the contradiction between the following parameters: ' harmful side effects' (the mercury in land fill from fluorescent tubes) and 'durability of a non-moving object' (achieving a competitive lamp-life for the product).

Studying the patent in more depth revealed that several inventions are brought together in this patent. These innovations solve contradictions between other parameters including 'brightness', 'waste of substance', 'amount of substance', and 'accuracy of manufacture'.

40 inventive principles

The novel manufacturing method described in the problem and solution hierarchy demonstrates the following of the 40 inventive principles described in TRIZ:

No. 7 Nesting: of the glass capsule inside the tube envelope;

No.28 Replace Mechanical: to break the capsule a high frequency electromagnetic field was used;

No. 37 Thermal Expansion: the difference in the coefficients of heat expansion of the metal wire and the glass capsule cause mercury to be released.

6.7.1.3 Conclusions from this study

The patent studied shows that the environmental issues are present at the system level of the problem hierarchy. This supports other sources in eco-innovation that emphasise the need for top-down management commitment for eco-innovation (Cramer & Stevels, 1997).

Moving down the problem hierarchy, the environmental element disappears. The problems are ordinary technical problems that could be defined as conventional technical or physical contradictions.

This study was a useful warm-up exercise for creating worked examples. The tools were not used to *generate* ideas but instead inventive principles were *matched* to some of the inventive solutions found. The tools evaluation table (explained in figure 6.7) cannot therefore be included as part of this study.

6.7.2 Domestic dishwasher study

The product chosen for this study was the automatic domestic dishwasher. This study followed the fluorescent tube lighting study described in section 6.7.1. That initial investigation helped to define the following steps for this study:

- Description of best environmental design practice;
- General technology maturity study;
- Study of a selected series of patents to determine the focus of design efforts;
- Construction of a 'problem hierarchy model';
- Selection and application of TRIZ tools;
- Discussion of TRIZ tools used.

6.7.2.1 Analysis conducted

Best environmental design practice

Initial investigations showed that the automatic domestic dishwasher is a relatively recent phenomenon. There is still a large proportion of first-time dishwasher buyers. The 'take-off' of this product is, in part, due to the improved performance of the product; some machines can now claim to be more energy and water efficient than washing dishes by hand. A second contributor to this phenomenon is social; the increase in families where both partners work means that time for domestic chores has decreased and disposable income has increased.

In 1995 a major study was carried out that described the long-term efficiency targets for domestic dishwashers (Van Holstein & Kemna, 1995). This report suggested many design strategies for the environmental improvement of the dishwasher. These strategies were analysed in terms of 'increased cost' versus 'payback time'. Strategies that achieve a payback time within the product lifetime are preferable. However, a number of dishwashers launched in the late 90's include environmental features that probably do not achieve a payback time within the product lifetime. This can be explained by consumer demand for machines that achieve a high Eco-label status, irrespective of the extra costs incurred.

In 1997 the Australian company Southcorp Appliances enhanced its expertise in dishwasher design by taking part in the EcoReDesign program (Gertsakis, Lewis & Ryan, 1997). They undertook strategic product development, Life Cycle Analysis, and design for disassembly and recycling. This best-practice case study highlighted the most important design issues for dishwashers: maximising energy and water efficiency. The project resulted in the development, design and launch of the Dishlex Global Range dishwashers, which were awarded the appliance industry award for the best white-good in 1997.

European Eco-labels help set environmental standards for various consumer goods. The Eco-labels are based on the best academic research and extensive collaboration with industry to ensure that standards are achievable (European Commission, 1998). The European Eco-label for dishwashers confirms a focus on 'energy and water in use' (Bjerregaard, 1998).

Technology maturity study

TRIZ includes several technology maturity tools, which help determine whether the best strategy for a product might be optimisation or innovation. The application of these tools then helps to determine the selection of TRIZ tools relevant to the creation of a 'better' design solution. S-curve analysis is one of the ways of determining technology maturity where 'value' is measured against time (Mann, 1999). Different metrics can be used to determine 'value' however a general sequence of product development can be described, as shown in figure 6.11.

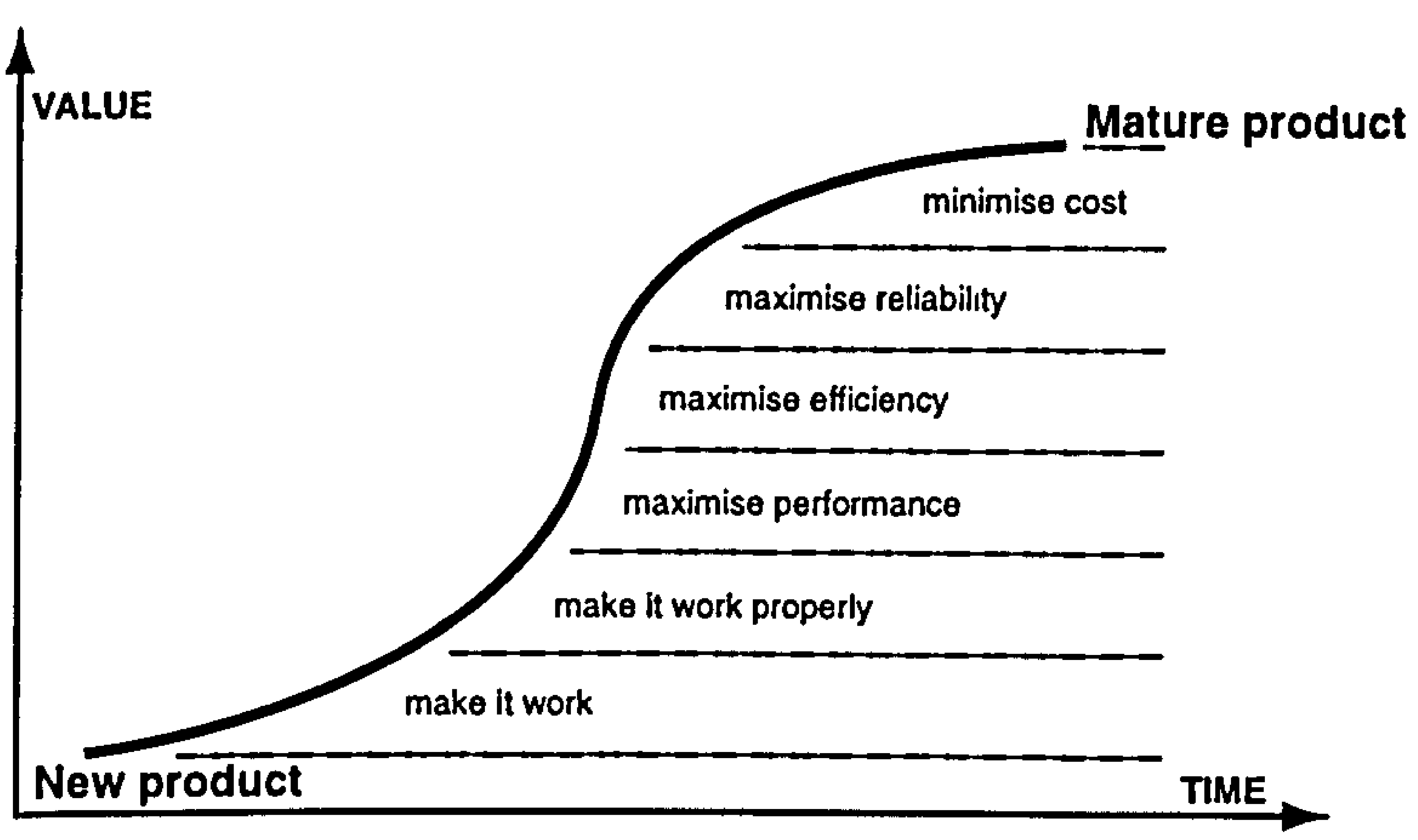


Figure 6.11: Typical invention focus S-curve, after Mann (1999)

An S-curve analysis of a collection of patent abstracts shows that the technology of the dishwasher has not yet reached maturity. In the late 90's (from 1998-1999) we start to see more reliability patents and the first patent to reduce cost.

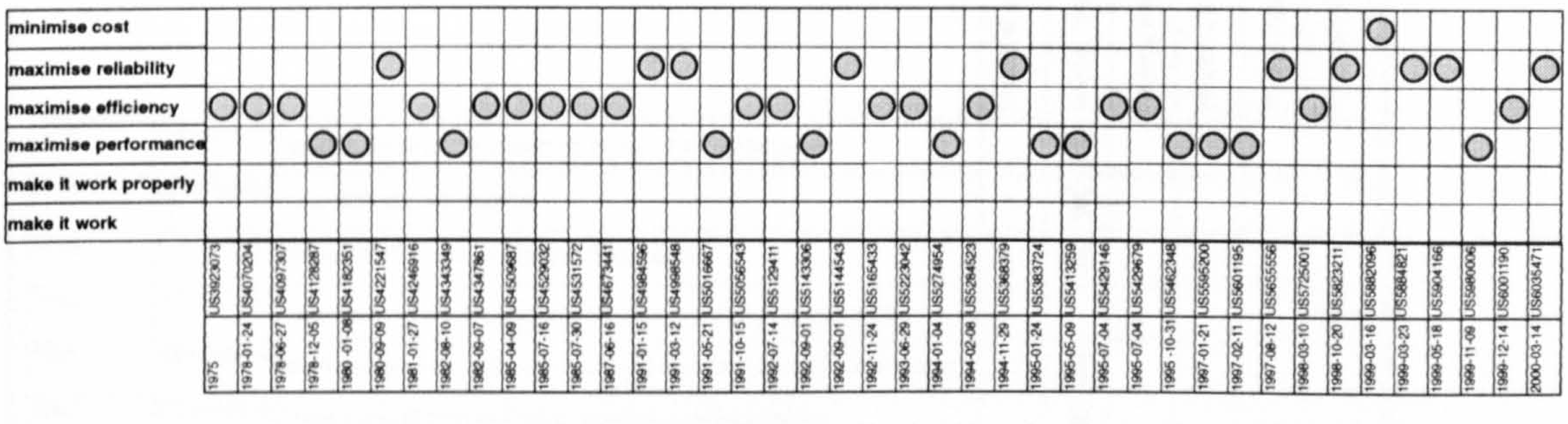


Figure 6.12: Patent collection of dishwashers studied, dots indicate invention focus

The analysis in figure 6.12 does not show a clear correlation with the invention S-curve described in figure 6.11. This may be due to the collection of patents studied. The criteria for selecting the patents were based on their potential for environmental improvement, which will be discussed in the next section. The patents often describe new features or improvements to existing sub-assemblies of the dishwasher, however, when scoring the patents their contribution to 'value' improvement to the whole dishwasher needed to be assessed.

Patent overview

Figure 6.13 shows the Dishwasher patent collection studied, crosses indicate the potential environmental improvements resulting from each invention.

			Eco-innovation headings					
			material used per unit service	energy used per unit service	hazardous substances emitted	waste not Eco-efficiently recycled	scarce ordepleting resources used	functional units in the product
1975	US3923073	Means for heating incoming water in a dishwasher		X				
1978	US4070204	Low-energy dishwasher		X				
1978	US4097307	Fill control for an automatic dishwasher		X				
1980	US4221547	Resilient mount for dishwasher motor and pump assembly						X
1981	US4246916	Dishwasher with steam generating heater and cold water input		X				
1982	US4343349	Heat pipe device and heat pipe fabricating process		X				
1982	US4347861	Dishwasher soil separator		X				
1985	US4509687	Multiple spray distribution system for a domestic dishwasher		X				
1985	US4529032	Method of and apparatus for recovery of waste energy		X				
1985	US4531572	Method of and unit for recovery of waste energy		X				
1987	US4673441	Dishwashing method: controlled inlet valve for supplying cleansing liquid into the sump		X	X			
1991	US4984596	Operating device for a dish-washer						X
1991	US4998548	Self-cleaning filter for a dishwasher						X
1991	US5056543	Device for drying dishes in a dishwasher		X				
1992	US5129411	Liquid level control arrangement for a dishwasher		X				
1992	US5165433	Soil separator for a domestic dishwasher		X				
1993	US5223042	Washing process for an automatic dishwashing machine		X	X			
1994	US5284523	Fuzzy logic control method for reducing water consumption in a machine for washing articles		X				
1994	US5368379	Dishwasher chassis: a part of the shell comprising the bottom of the tub						X
1995	US5413259	Device for repeated, automatic metering of doses of a powdered detergent in water-conducting cleaning machines		X	X			
1995	US5429146	Dishwasher connectable for single-phase alternating current connection		X				
1995	US5429679	Method for operating a low energy domestic dishwasher		X				
1995	US5462348	Dishwasher utensil tray		X				
1997	US5595200	Dishwasher with vertically adjustable basket		X				
1997	US5601195	Basket with a movable divider for a dishwasher		X				
1997	US5655556	Dishwasher with rotating spray agitator		X				
1998	US5725001	Dishwasher with pH-controlled program pre-selection			X			
1998	US5839097	Electrical home appliance: system design concept		X				
1999	US5882096	Dishwasher: fastening being less complicated and therefore more cost-effective and having better stability						X
1999	US5884821	Device for dispensing detergent, particularly for dishwashers						X
1999	US5904166	Spray arm support for front-loading dishwashers						X
1999	US6001190	Reduced energy cleaning appliance		X				
1999	US6035471	Method for detecting impermissibly high scaling in a water-conducting domestic appliance		X				X

Figure 6.13: Dishwasher patent collection studied

From figure 6.13 it is possible to observe a shift in innovation focus. Until the 1998 the patents mainly record: efficiency improvement of the dishwasher (column 2: energy used per unit service) and some optimisation in the amount of detergent (column 3: hazardous substances emitted). From 1999 onwards the patents record more developments in lengthening the product lifetime and decreasing time before maintenance or repair (column 6: number of functional units in the product). Columns 1,3 and 4 all concern the actual material in the product itself, no patents record a focus on these issues, confirming that the main environmental impacts of the dishwasher are its use of energy, water and detergent. This table summarises the manufacturers' considerable design efforts to reduce the environmental impact of their products.

Problems and solutions hierarchy

The Van Holstein and Kemna (1995) report states the main factors affecting the automatic cleaning of dishes are: time, temperature, detergent and mechanical action. However, the report also specifies that at a given volume and composition of the total wash load per period of time (per week/year) the efficiency of the dishwasher will depend on the following three parameters:

- Consumer behaviour
- Machine dependant variables
- Parameters which depend on the energy/infrastructure supply

The problems and solutions hierarchy shown in figure 6.14 is broken down under those headings. The machine dependant variables are broken down further, based on the descriptions of best environmental design practice:

- Increasing the product life-time
- Reducing detergent usage
- Reducing water usage
- Reducing heating energy

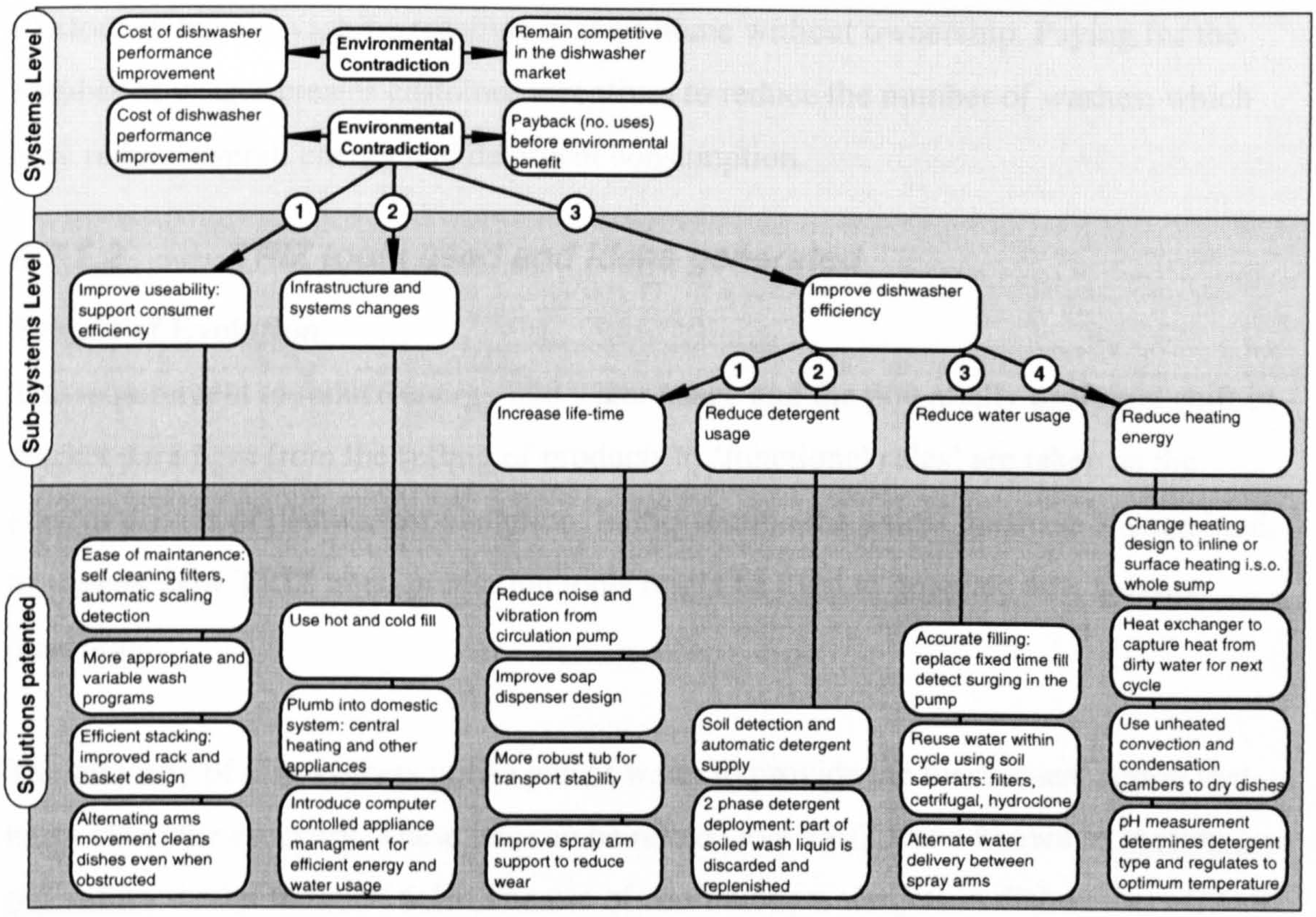


Figure 6.14: Problems and solutions hierarchy summarising patented solutions from best-practice environmental design for dishwashers

Most work has gone into reducing the heating energy as this represents 90% of the energy consumed by dishwashers. The main motivation to reduce the volume of water used is due to the subsequent reduction in heating energy required for that smaller volume.

Another major factor influencing the efficiency of the machine is the usability of the machine. The Eco-label highlights the need for companies to encourage responsible user behaviour by including special instructions for optimal use of their product. Manufacturers have focused on: improving the stacking efficiency; ease of maintenance to prevent breakdown; and optimisation of the wash programmes offered.

Relatively few manufacturers have patented infrastructure and systems changes. Bosch (US patent 5839097) and Electrolux (Electrolux, 2000) are exceptions and have started research in these areas. Electrolux have launched a new business model for clothes washing called 'functional sales' in which they offer customers a pay-per-wash scheme.

Customers have a washing machine in their home without ownership. Paying for the number of usages creates customer incentives to reduce the number of washes, which may reduce overall energy and detergent consumption.

6.7.2.2 TRIZ tools used and ideas generated

Trends of Evolution

The requirement to reduce energy and water usage and the potentially profound shift in market paradigm from the selling of products to 'functional sales' are taken as the current drivers of dishwasher evolution. In this section the patent database is examined, to suggest how TRIZ trend prediction tools might be used to generate new solution directions.

The majority of dishwashers utilise jets of water to provide the mechanical action that helps clean the crockery. These jets can be related to a TRIZ trend known as rhythm co-ordination shown in figure 6.15. The use of continuous water jets in dishwashers is still common, and can be classified as a system at the first stage along the evolution path. The trend suggests the use of pulsations to be a good next evolution step, and indeed the first washers using pulsed jets are beginning to emerge. Southcorp Appliances launched their Dishlex Global range which includes their Hydrapulse® wash action. The advantage gained by moving to a pulsed jet is that cleaning effectiveness is improved and the amount of water required is reduced. Other manufacturers have been working on similar strategies to reduce water consumption. In 1985 General Electric patented a system that would alternate the delivery of water to the upper and lower spray arms (US patent 4509686) to reduce the overall flow rate and thereby the water consumption. In 1997 Electrolux-Zanussi patented (US patent 5655556) a system that would alternate delivery of water to two nozzles on the same arm with opposite thrusts.

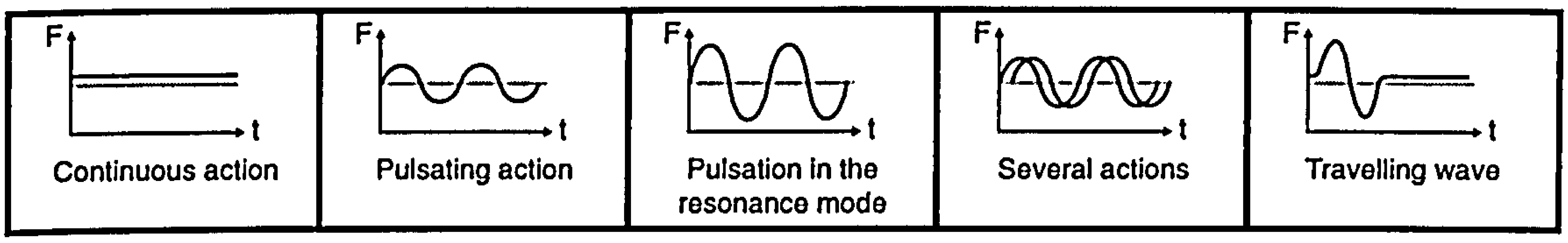


Figure 6.15: Rhythm co-ordination trend (after Invention Machine, 1995)

The next stage suggested in the rhythm co-ordination trend would be systems that include resonance principles. However, no dishwasher manufacturers have yet developed such systems, though these have been developed and implemented for other jet cleaning applications such as high-pressure ship hull cleaning. ServoJet® Interrupted Jet nozzles developed by Dynaflow Inc., employ passive acoustic resonance and have been successfully applied in ship hull cleaning (Chahine, 1996).

The controllability trend shown in figure 6.16 suggests that benefits may be derived by adding feedback where it is not currently present. This trend is demonstrated clearly in dishwashers where first models used simple fill times to achieve the right amount of water for their cycles. This fill time had to take account of the lowest acceptable water pressure that might be encountered in a home, in most homes therefore, the machine would be overfilling with water. In 1978 an intelligent fill control was developed (US patent 4097307). A similar but more recent version of the invention uses Fuzzy logic circuitry to sense the diminished cavitation in the freshwater pump (US patent 5284523). Several other aspects of the dishwasher are seeing an increased level of intelligence in the feedback of the system such as: measured pH-level of the wash liquid and subsequent adaptation of wash program (US patent 5725001); measurement of turbidity and hence determining threshold values for de-scaling procedure (US patent 6035471); measurement of particulate soil concentration and automatic selection of appropriate wash cycle (US patent 4673441).

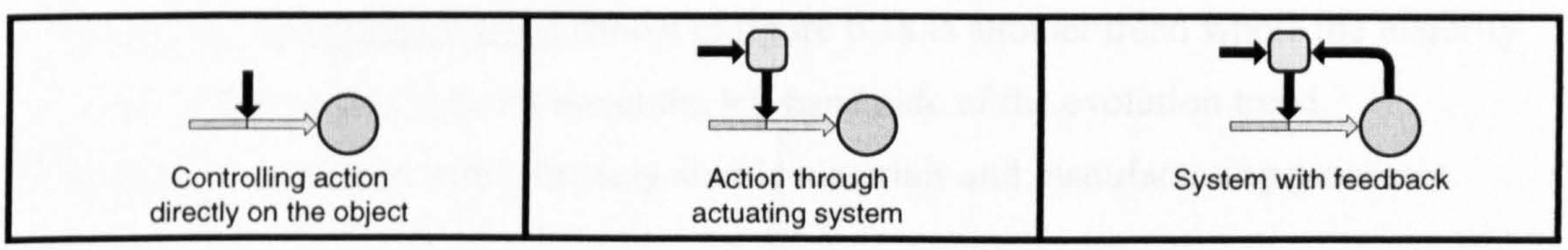


Figure 6.16: Controllability trend (after Invention Machine, 1995)

This trend highlights the possibilities for further feedback in the system which would optimise energy and water usage. One concept might be to develop machines which measure and feedback the cleanliness of the contents throughout the program and automatically optimise the timing of the wash cycles.

The substance and object segmentation trend shown in figure 6.17 suggests profound changes in dishwasher systems. The majority of current systems operate at the 'liquid' stage of this evolution trajectory. Increasing segmentation by atomising water droplets for example, would reduce water usage. Further moves to gaseous solutions, using steam for example, might offer additional benefits.

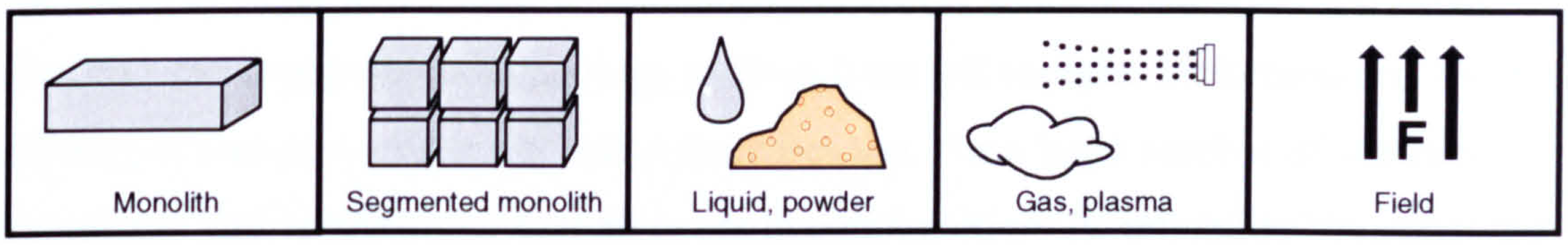


Figure 6.17: Substance and object segmentation trend (after Invention Machine, 1995)

Looking at this trend suggests that the use of 'fields' would be the next evolutionary stage. The 'fields' solution trigger suggests a number of new design concepts:

- use of ultrasonics, a well-established method in other industries of improving water atomisation;
- use of electrostatics, a potential method for encouraging charged water droplets to find their way onto dishes;
- use of microwaves, as an alternative way of heating the water provided the problem of metallic parts and crockery can be overcome.

The surface segmentation trend shown in figure 6.18 is another trend where the majority of today's dishwasher systems are at the left hand side of the evolution trend. Dishwashers are made with relatively simple materials and manufacturing processes.

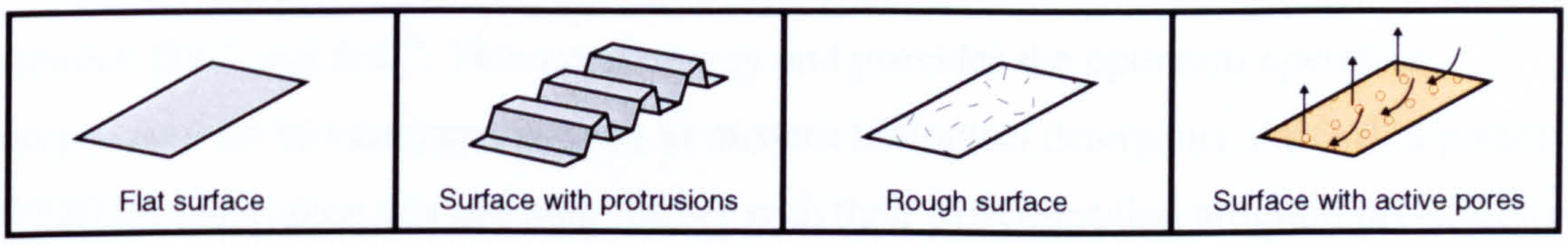


Figure 6.18: Surface segmentation trend (after Invention Machine, 1995)

A simple idea developed from this trend might be use of a Lotus Effect surface finish on the walls of the dishwasher or the dishes. The Lotus Effect is a biological system based on surface roughness caused by different microstructures. A Lotus Effect surface causes contaminating particles to stick to droplets of water which roll off the surface (Barthlott & Neinhuis, 1999). These surfaces would reduce the amount of detergent required and improve the run-off back to the sump, thereby reducing the water consumption in the dishwasher.

40 inventive principles

The majority of the technology evolution trends ensure that the 'benefits' and hence 'ideality' are increasing as technology evolves from left to right. Unfortunately, for the majority of trends, 'complexity' often increases too. For a large number of systems, complexity and reliability or durability are in contradiction. If 'reliability' becomes the pre-dominant design issue, then designers may be pushed to use the trends in a right-to-left direction, and thus potentially degrade some of the performance benefits.

A good strategy in this scenario is to revert to using the contradictions matrix. Mann and Hughes (1999) have examined which of the 40 inventive principles are most likely to be recommended by the contradictions matrix in situations where 'reliability' is to be improved. These are the principles numbered 35, 10, 11, 3, 28 and 40.

Some of the more recent patents illustrate good examples of manufacturers addressing these reliability issues with the suggested principles:

<u>Principle 35: Change of Physical and Chemical Parameters – suggests change of aggregate state, change of concentration or consistency, change of flexibility, or change of temperature.</u>

Most dishwashers have an 'eco' or 'bio' setting which keeps the wash temperature between 50C° and 55C°. This saves energy and provides the optimum operating temperature for bio-enzymes present in modern biological detergents. AEG (US patent 5725001) have taken this one step further with their pH-controlled program pre-selector which automatically selects the wash program temperature by measuring the pH and thereby determining the detergent type (biological or non-biological).

Principle 10: Prior Action – suggests that if your object is subjected to harmful factors in its environment, create conditions that will protect the object from those harmful factors beforehand.

One recent example of such a prior action principle is US patent 6035471: 'a method for detecting impermissibly high scaling in a water-conducting domestic appliance'. This feedback device will detect levels of scaling and will warn the user to de-scale on time. De-scaling regularly will improve efficiency and improve product lifetime.

Principle 11: Beforehand Cushioning - suggests that if your object is unreliable, create conditions in advance that will protect the object.

Several manufacturers have been working to overcome problems created by clogged spray arms and filters. Various types of self-cleaning filters have been developed to reduce routine maintenance and increase time before overhaul maintenance. One example is US patent 4998548 which combines course and fine filters. A second example of such a 'beforehand cushioning' principle is a new manufacturing method for the dishwasher chassis (US patent 5368379), which makes the dishwasher more robust during transport and solves the majority of leaking problems.

Principle 3: Local Quality - suggests making the object non-uniform, making the environment non-uniform, or if multiple functions are to be performed, divide the object into parts according to those functions.

One recent example of dividing the dishwasher into parts according to functions required can be seen in the Dishlex Global dishwashers developed by Southcorp. One of their features is the gentle wash action on the top shelf to safeguard fragile items and the more vigorous wash action applied to pots and pans on the bottom shelf.

Having matched some of the recommended principles to recent developments in dishwashers, the following principles stimulated ideas that have not been exploited by manufacturers yet.

Principle 28: Mechanics Substitution - suggests replacing mechanical solutions with other physical solutions; acoustic, optical, magnetic, thermal.

This principle suggests significant technological changes in the system, similar to the concepts proposed in the 'substance and object segmentation trend' before. These new concepts begin to question the basic cleaning factors set out in the problem hierarchy and solution hierarchy: time, temperature, detergent and mechanical action. Implementing radical new technologies will mean that automatic dishwashing begins to move further away from the simulation of the washing of dishes by hand.

Principle 40: Composite Materials - suggests the use of composite materials instead of uniform ones.

As mentioned before, the materials and processes involved in the manufacture of dishwashers are relatively basic. Materials have been predominantly selected for their ability to endure prolonged exposure to the harsh detergents used. The use of composite materials is normally discouraged in environmental design. However, their use in non-stick crockery, such as the Lotus Effect surfaces suggested earlier, would 'soften' the detergents required and thereby offer a much wider range of possible materials for the internal design of dishwashers. This would mean that the designer would be able to specify cheaper, lighter, and more recyclable materials.

6.7.2.3 Conclusions from dishwasher study

In this study, four of the technological evolution trends and six selected inventive principles were employed. Some of the changes suggested by the trends and principles were exemplified in recent innovations whilst others were genuinely new suggestions for further changes to the systems within the dishwasher. From the patents studied it has become apparent that dishwashers are undergoing significant research and development as the potential market size continues to grow. Application of both trends and inventive principles show potential to accelerate the development of the dishwasher.

Table 6.5 shows that the tools generated some innovative – original and appropriate – solutions with the potential for reducing the environmental impact of the dishwasher. The ideas generated were mostly at the sub-system level and therefore did not radically change the way the dishwashing function would be fulfilled.

tool used:	idea summary:	original: not seen in current versions	approriate: could be taken up in existing industry	sub-system: new elements/parts of an existing dishwashing device	system: a new type of dishwashing device	super-system: a different way of domestic dishwashing	incremental: small improvement or redesign of existing dishwasher						radical: a step-change in the way the dishwashing function is fulfilled	environmentally relevant: shows potential to reduce the environmental impact of dishwashing
rhythm co-ordination trend	Hydrapulse® wash action	no	yes	yes				X						yes
rhythm co-ordination trend	alternate upper and lower spray arms	no	yes	yes				X						yes
rhythm co-ordination trend	same arm with opposite trusts	no	yes	yes				X						yes
rhythm co-ordination trend	acoustic resonance jets	yes	yes	yes						X				yes
controllability trend	fuzzy logic fill controls	no	yes	yes				X						yes
controllability trend	pH-level of the wash liquid	no	yes	yes				X						yes
controllability trend	measurement of turbidity	no	yes	yes				X						yes
controllability trend	particulate soil concentration	no	yes	yes				X						yes
controllability trend	content cleanliness throughout program	yes	yes	yes				X						yes
substance and object segmentation trend	atomising water droplets	yes	yes	yes			X							yes
substance and object segmentation trend	gaseous solutions: steam	yes	yes	yes			X							yes
substance and object segmentation trend	ultrasonic water atomisation	yes	yes	yes					X					yes
substance and object segmentation trend	electrostatics charged water drops	yes	yes	yes					X					yes
substance and object segmentation trend	microwaves to heat water	yes	yes	yes					X					?
rhythm co-ordination trend	lotus effect dishes	yes	yes	yes						X				yes
rhythm co-ordination trend	lotus effect dishwasher walls	yes	yes	yes				X						yes
principle 35: change of physical and chemical parameters	pH-controlled detergent type check	no	yes	yes				X						yes
principle 10: prior action	automatic descaling warning	no	yes	yes				X						yes
principle 11: beforehand cushioning	self cleaning filters	no	yes	yes			X							yes
principle 11: beforehand cushioning	transport robust dishwasher chassis	no	yes	yes			X							yes
principle 3: local qualtiy	different wash action on shelves	no	yes	yes				X						yes
principle 28: mechanics substitution	move away from simulating hand dishwashing	yes	?		yes					X				?
principle 40: composite materials	high tech crockery, lighter recyclable materials inside	yes	yes	yes				X						?

Table 6.5: Evaluation table of outcomes from tools used in domestic dishwashing study

Not many ideas were created at the system and super-system level. The TRIZ expert said that such concepts could have been created if he had been briefed more specifically to look at means other than 'dishwasher' for delivering the function 'clean dishes'. The study concluded that there is still work to be done on stimulating the use of TRIZ tools at higher levels of the system hierarchy.

6.7.3 CHP system study

This study was conducted for a conference on sustainable service systems and aimed to investigate what TRIZ could contribute to the debate. The paper provided a case study on Combined Heat Power (CHP) systems, to illustrate some of the concepts and tools from TRIZ (Mann & Jones, 2001).

As part of the analysis, a close look was taken at TRIZ's ideality equation when the market drivers shift from 'product provision' towards 'service provision'. The paper demonstrates the use of some TRIZ tools in the different market situations.

6.7.3.1 Analysis conducted

Best environmental design practice

Recently there has been a steady increase in the development of portable generator technologies, as interest in small scale Combined Heat Power generation increases. Combined Heat Power (CHP) systems are systems that use gas-powered generators to generate electricity whilst simultaneously harnessing the high-grade waste heat. This waste heat can be used in industrial processes, community heating or space heating. The second efficiency gain is due to the avoidance of electrical transmission losses because electricity is generated on site. CHP is a very efficient technology for generating electricity and heat together.

In a CHP system, the balance of heat and electricity output is optimised to meet the particular site requirements. The newest installations can achieve a reduction of CO2 emissions of over 50 per cent compared with generation from coal-fired power stations.

Historically, the main factor preventing the exploitation of stand-alone high-speed turbo-generators has been their low power density. However, their efficiency has been significantly improved by the use of rare-earth magnet materials and the development of generators capable of running at very high speeds. Less material is used in their construction and the high-speed capability offers significantly greater flexibility of fuel types. The typical power density of such a turbo-generator is around 5 to 10 times better than a conventional diesel driven generator.

General barriers to the take-up of CHP systems are: high initial investment, long lead times for installation, and high maintenance costs. However, in situations with high heat demand, such as hospitals, leisure centres, hotels and industrial sites with process heating requirements - especially the chemical, brewing and paper industries - the technology can have short payback times.

By the end of 1999 about 1300 CHP systems were installed in the UK generating over 4000 MWe. The UK Government is promoting CHP further through the Energy Efficiency Best Practice Programme and its Draft Programme for Climate Change which proposes a CHP target of 10,000 MWe by 2010 (DETR, 2000). The UK government has also identified 'energy from waste using CHP' as a renewable resource.

There are several successful examples where wastes such as sewage gas and municipal solid waste (MSW) have been used to fuel CHP systems. One example quoted in a recent environmental report is that of Southern Water's biogas-fuelled CHP system at Ashford, that will generate in the region of 3.3 GWh of renewable energy per annum (Scottish Power, 2001).

The main features of a typical CHP system shown in figure 6.19 are:

- the generator;
- the prime mover;
- some form of heat exchanger to recover waste heat from the gas-turbine exhaust;
- power electronics and control systems.

The prime mover in this case study is a single shaft gas turbine comprising: a compressor, combustor and turbine.

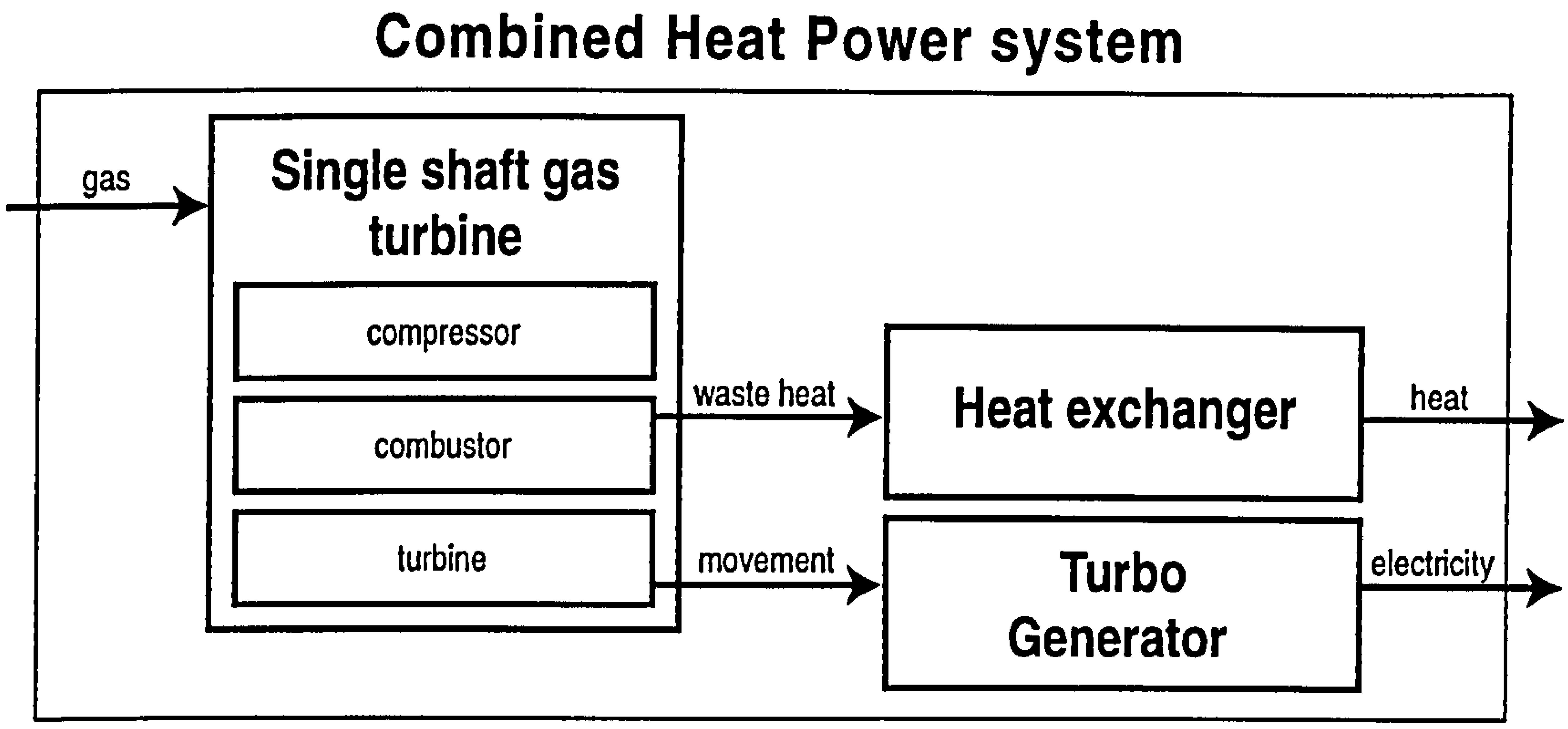


Figure 6.19: Schematic of Combined Heat Power (CHP) system

Ideality study

As described in section 6.1.1 the 'ideality' concept from TRIZ states that systems will evolve towards ideality, which can be expressed as a qualitative equation of benefits divided by the sum of costs and harms.

$$Ideality = \frac{benefits}{(costs + harms)}$$

This part of the analysis explores changes in the ideality equation when the market shifts from product-provision towards service-provision and makes comments about how that affects the designer's approach to the generator. The three market conditions explored in this study - 'product-service', 'use-service', and 'result-service' -are defined by Hockerts (1999) in a paper on eco-efficient services.

Generator Design Implications in a Product-Service Market

In designing systems for the 'product-service' market - where the service is simply additional to the product sold - designers are commonly driven to look for a low first-cost solution. This emphasis is strong in cases where the product technology is still maturing. In this case the ideality equation would reflect that emphasis as follows:

$$Ideality = \frac{\text{acceptable benefits}}{(\text{lowest first cost} + \text{compliant harm})}$$

'Acceptable benefits' are the good things that customers receive or expect to receive from the energy system. The generator offers a new benefit of 'portability', but the premium that customers are thus far willing to pay for such a benefit are seen to be relatively small except in a few tight niches. 'Compliant harm' in this case means that the design is compliant with prevailing emission legislation and impending recycling legislation.

Generator Design Implications in a Use-Service Market

The shift from a product-based to a service-based market is affecting a growing number of products and processes (Pine & Gilmore, 1999). A 'use-service' is one where the provider no longer sells a product, but its use. Many manufacturers are struggling with the subtle - but often profound - shift from a lowest first-cost to a lowest life-cycle-cost design paradigm. The ideal final result for manufacturers in a traditional product-service market, is a product that requires replacement soon after its warranty expires. This short-term strategy gives the manufacturers the maximum return on their investment. However, in a use-service market the service provider continues to own the product and the emphasis may therefore shift towards maximising reliability of the product. A longer-lasting product may now be the manufacturer's ideal final result. The most important design contradictions will probably centre on reliability issues. The ideality equation for use-services may have the following emphasis:

$$Ideality = \frac{acceptable\ benefits}{(lowest\ life\ cycle\ cost + compliant\ harm)}$$

Generator Design Implications in a Result-Service Market

The shift from use-service to result-service is one where the provider guarantees a certain result regardless of the material product. When providing a result service the material product not only needs to be reliable and long-lasting but it is also in the service providers' best interest to achieve the optimum efficiency throughout the product life-cycle. In this market, the design emphasis for ideality in the material product would commonly shift to:

$$Ideality = \frac{maximum\ benefits}{(lowest\ life\ cycle\ cost + compliant\ harm)}$$

To move towards ideality in the design of a result-service, there needs to be a fundamental shift of emphasis to include the design of the super-system. The CHP unit itself is now a component in the design of the system providing heat and power.

Defining the system hierarchy

A problems and solutions hierarchy is not drawn up for this study. However, it is necessary to define the system hierarchy in the example in order to organise the TRIZ output generated by two different TRIZ practitioners.

The super-system in this case is defined as a Self-sustaining Energy Management System for use in a district community-housing scheme described in figure 6.20. The Combined Heat Power (CHP) unit is fuelled by methane captured from an anaerobic sewage digester, itself processing the 'waste' from the community housing. The heat from the CHP unit is used to steam lance the biomass waste from the community to create high quality compost. The remaining low-grade heat and waste gas is piped into the glasshouse, where it is used to promote plant growth - the plants in turn 'cleaning' the waste gas (Care, 1999).

Energy Management System

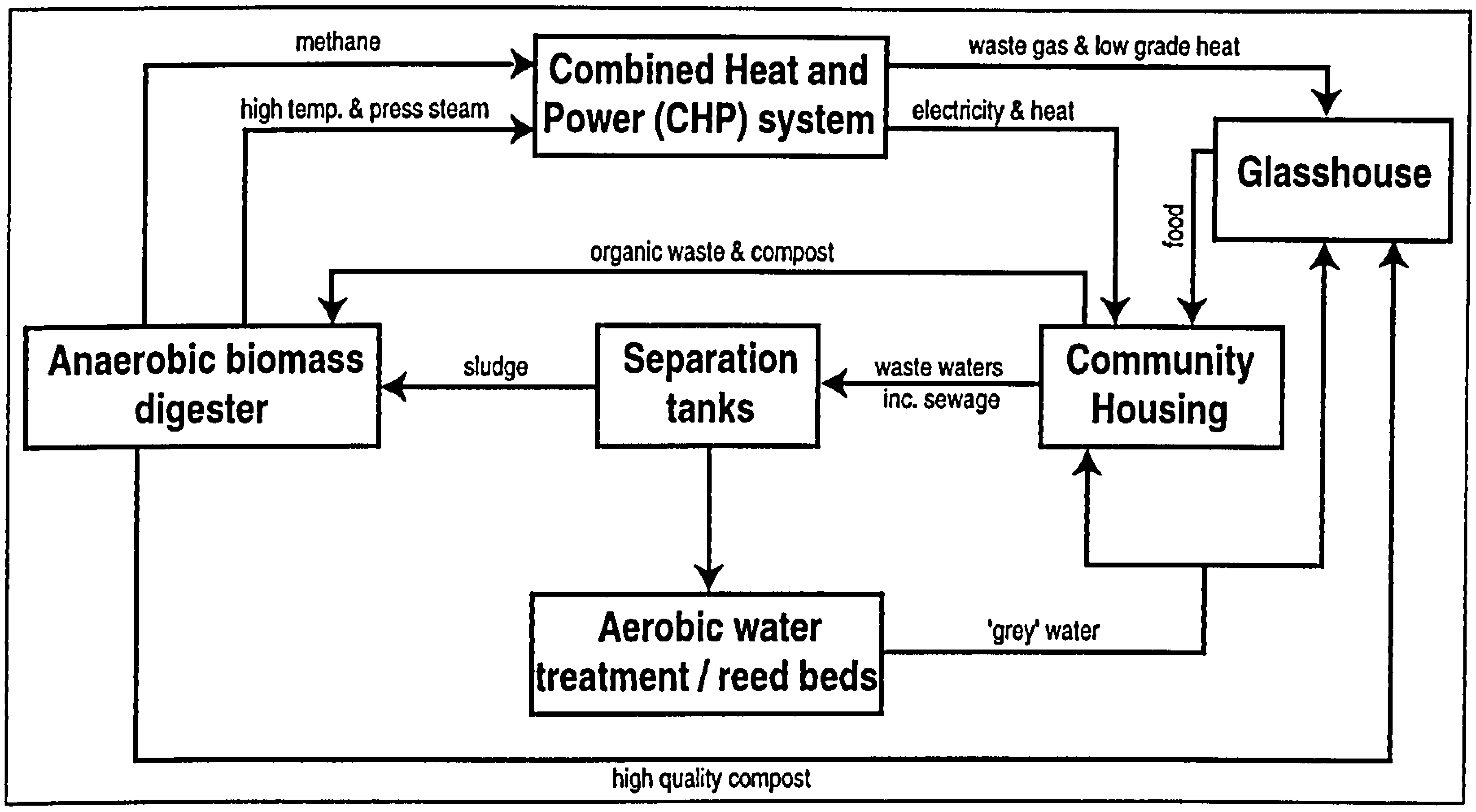


Figure 6.20: Schematic of self-sustaining energy management system (after Care, 1999)

The system was defined earlier as the combined heat power system and described in figure 6.19. The sub-systems in this case are defined as the turbo-generator, the prime mover and the heat-exchanger elements.

6.7.3.2 TRIZ tools used and ideas generated

Trends of evolution

The trends of evolution are used at the sub-system level to generate ideas for the combustor design. Figure 6.21 shows the current combustor design which is examined and is matched to the known TRIZ trends. The trends that show best correspondence with the combustor design are examined in order to identify in which aspects the design is still at the very beginning of its evolutionary potential. The under-pinning concept of 'evolutionary potential' is that systems have the potential to evolve all the way along each of TRIZ's technology trends.

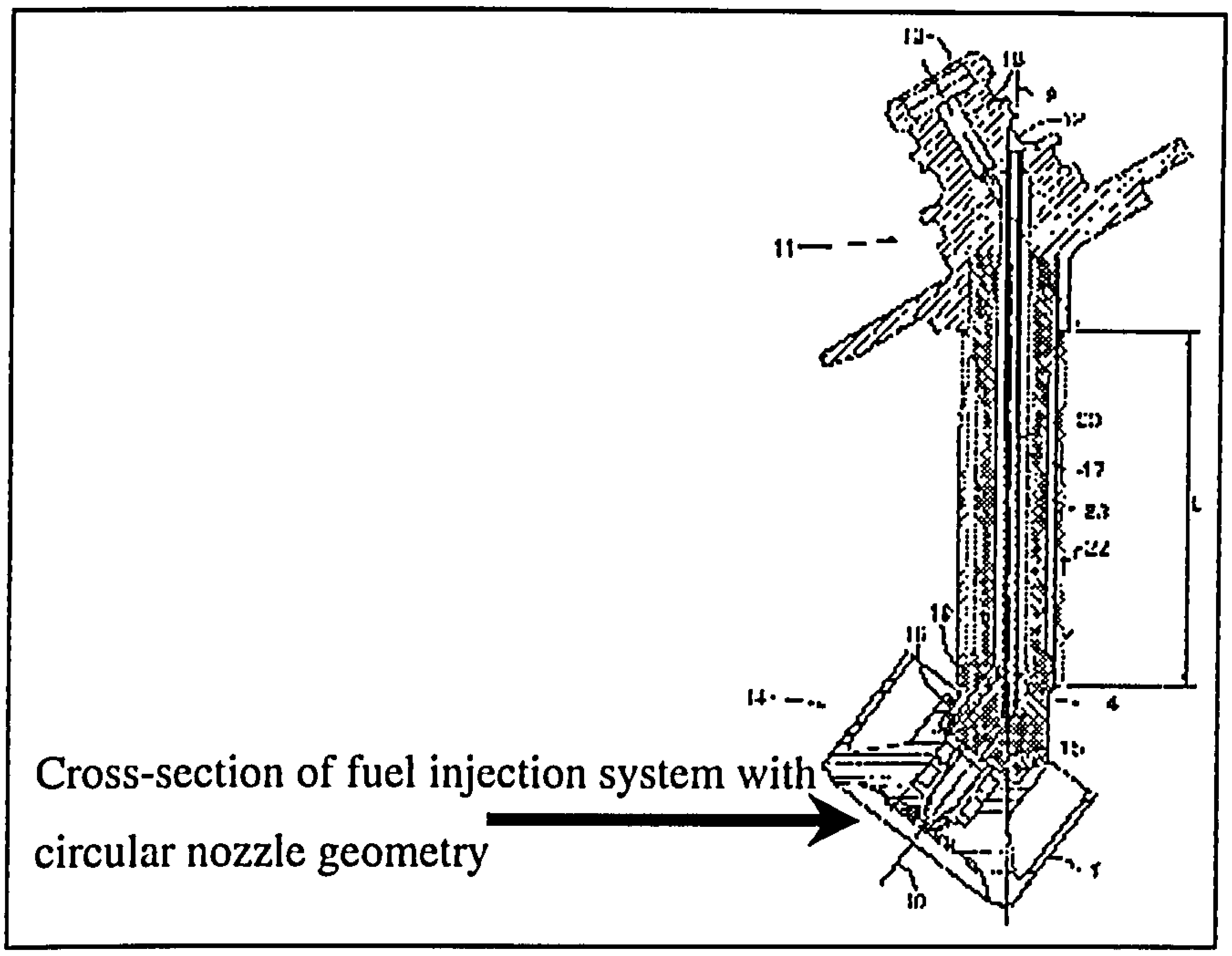


Figure 6.21: Current state-of-the-art combustion system fuel injection design

The first trend used is the 'geometric evolution' trend shown in figure 6.22. In combustion design, it is well known that the fuel-air mix of, and the production of, the smallest possible fuel droplet size is critical to the realisation of low emissions - including CO, NOx, and UHC emissions. The geometric evolution trend suggests that the fuel-air mixing problem could be tackled by evolving the nozzle injector from its current 'point' to a line or plane-based design. The design shown in figure 6.22 would increase the mixing area by more than a factor 5 while leaving other essential design parameters such as supply pressure and accuracy unchanged.

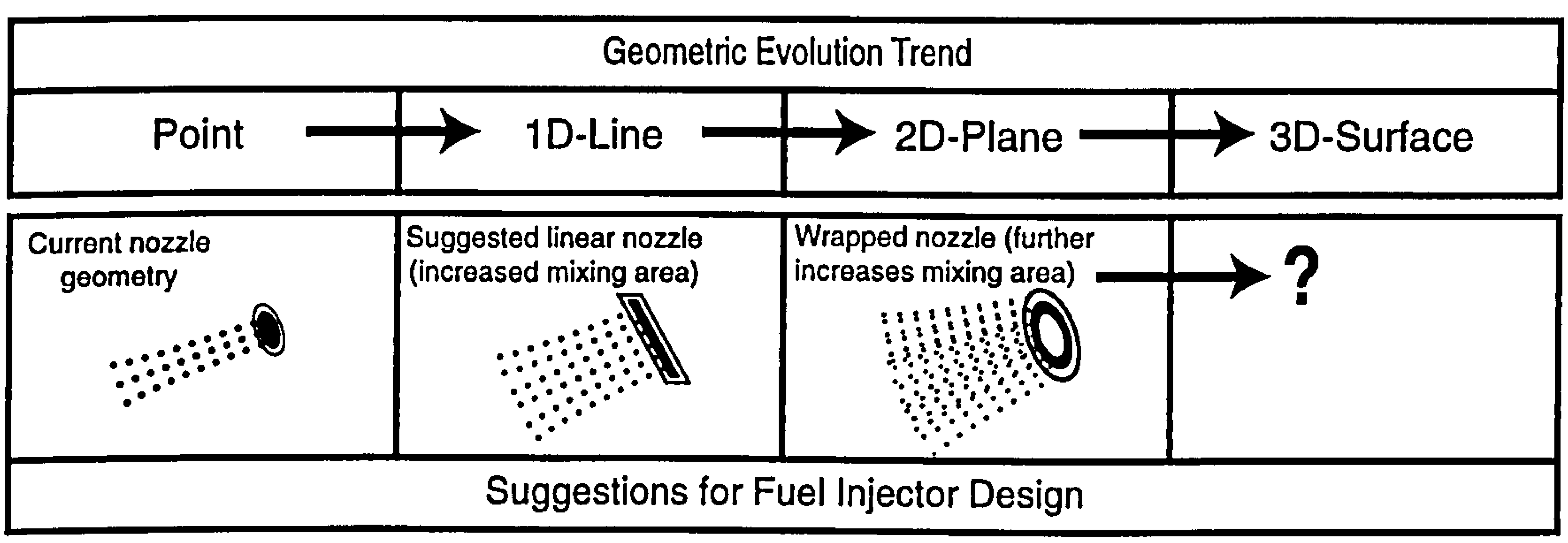


Figure 6.22: Geometric evolution trend and evolved fuel injector design

The second trend – 'rhythm co-ordination' shown in figure 6.23 - shows that benefits increase as systems evolve from continuous, to pulsed, to resonant actions. This trigger prompts an examination of the patent database for cases where pulsation and resonance have been used to generate beneficial action in related technologies. This search provided the idea of using ultrasound via a small piezo-electric vibrator. The piezo-electric vibrator is used to smash drops of liquid into sizes 10 times smaller than would be possible using conventional means (US patent 5122053).

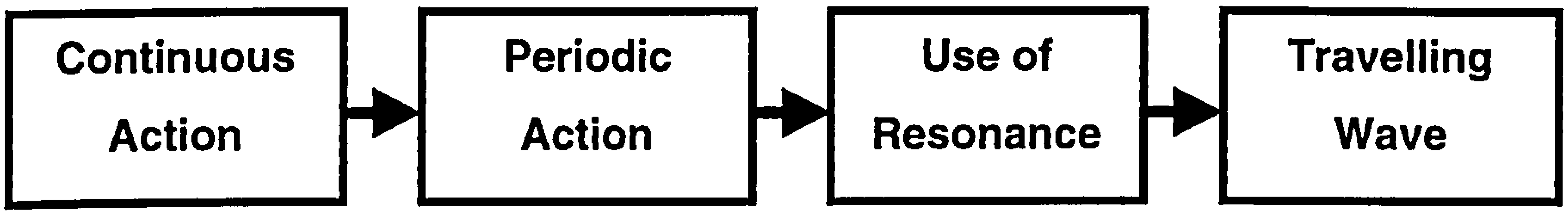


Figure 6.23: Rhythm co-ordination evolution trend (after Creax, 2001)

Taken together the non-point injector nozzle combined with an ultrasound vibrator could convert the current combustor system and offer emission improvements exceeding current regulation at negligible cost. This design concept is currently undergoing design and prototype evaluation.

Ideality

Ideality is used at the system level to generate ideas to improve the reliability of CHP systems. In this case the practitioner conducted a reliability study of the system determining the life-limiters within the system and identified the coupling between the prime mover and the generator as an important focus for innovation.

The coupling between prime mover and generator has some generic parallels with other industries. There are many 'high speed coupling' designs to be found in the patent database. The root causes of a coupling problem are non-alignment and out-of-balance forces. The TRIZ concept of 'ideality' points towards solutions where systems are 'self-aligning' and 'self-balancing'. A search of the patent database for solutions of this kind identified a number of potentially relevant solutions from other industries.

The first 'self-balancing' rotating system patent was granted in 1961 (US patent 3006690) but hardly anyone from outside the original industry - car wheels - took any notice for over 15 years. Several industries are now adopting the 'self-balancing' concept. Washing machine manufacturers, for example, traditionally insert large amounts of concrete into their products to balance the rotating drum. Now they are investigating a more elegant solution which removes the concrete and uses a 'self-balancing' technology. Such a 'self-balancing' technology may also benefit the turbo-generator design, where at present, even small amounts of change or damage (e.g. from foreign object ingestion) to components can result in massive balance problems.

Ideal final result statements

Ideal final result statements are used at the super-system level to develop a 'self-sustaining energy management system' for use in a district community-housing scheme. The use of the Ideal final result statements was distilled from the interview transcript described earlier under project 3 in section 6.6.

Ideal Final Result statements:	TRIZ tools subsequently used:
'To reduce waste to land-fill and provide free useable compost for the community'	
'An efficient organic waste collection system and how to produce a high quality compost in small batches quickly.' 'To retain nutrients within the local cycle.'	'Used **Function analysis** to identify harmful effects, **Resource analysis**
'To combine the sewage digester with combined heat power unit and accelerated community composter.' 'To have high efficiency and zero emissions.'	Identified **contradiction** between low temperature and high cycle times.
'To overcome health and safety issues with the output from the sewage digester'	Used **Little people** at the molecular level, UV solution to kill viruses (harmful effect identified)
'To change mind-set of water companies, to see themselves as nutrient recyclers as well as clean water providers.'	

Table 6.6: Ideal Final Result statements and subsequent TRIZ tools used (after Care, 1999)

The Ideal Final Result statements in table 6.6 show how the project evolved and how the different TRIZ tools are subsequently used to solve problems at both the super- and sub-system levels of the hierarchy. In this case the Ideal Final Result statements are used to focus the innovation effort; subsequently, various analysis or solution tools from TRIZ are employed.

6.7.3.3 Conclusions from this study

This study focussed particularly on the use of the ideality theory and Ideal Final Result statements from TRIZ. Three different ways of using 'ideality' were demonstrated by two TRIZ practitioners. First, the ideality equations were investigated to show that the design emphasis shifts from first-cost to life-cycle-cost to maximum-benefit as market drivers shift from product-service to use-service to result-service paradigms. Then, the ideality theory was used to generate ideas for the CHP system by pointing towards solutions where systems are 'self-aligning' and/or 'self-balancing'. Finally, the Ideal Final Result statements were used to focus the innovation effort alongside the use of other TRIZ tools.

The main aim of this study was to investigate what TRIZ could contribute to sustainable service systems. Table 6.7 shows that the tools generated some innovative – original and appropriate – solutions for CHP systems including ideas for a super-system such as a district community-housing scheme.

tool used:	idea summary:	original: not seen in previous versions	approriate: could be taken up in existing industry	sub-system: new elements/parts generator, prime mover, heat-exchanger, etc	system: a new type of combined heat power system	super-system: a new Energy Management System	incremental: small improvements or redesign of existing sub-system, system or super-system						radical: a step-change in sub-system, system or super-system	environmentally relevant: shows potential to reduce the environmental impact of heat and power generation
'geometric evolution' trend	line or plane injector nozzle	yes	yes	yes						X				yes
rhythm co-ordination trend	piezzo-electric vibrator to smash fuel drops	yes	yes	yes							X			yes
concept of 'ideality'	'self-balancing' coupling prime mover and generator	yes	yes		yes				X					?
ideal final result statements	reduce land-fill waste and provide free compost	yes	yes			yes				X				yes
ideal final result statements	high quality compost in small batches quickly	yes	yes			yes			X					yes
ideal final result statements	retain nutrients within the local cycle	?	yes			yes				X				yes
ideal final result statements	combine sewage digester, CHP unit and composter	yes	yes			yes						X		yes
ideal final result statements	make safe output from the sewage digester	no	yes			yes		X						yes
ideal final result statements	water companies as water providers *and* nutrient recyclers	yes	yes			yes						X		yes

Table 6.7: Evaluation table of outcomes from tools used in CHP system study

In this study the trends of evolution were used at the lower system levels and were able to suggest innovative improvements for parts of the CHP system. The Ideal Final Result statements at the super-system level generated ideas that did move the outcomes towards more radical solutions than in the dishwasher study.

6.7.4 Conclusions from the three studies put together

The first study confirmed the TRIZ premise that innovative projects eliminate contradictions, as several contradictions identified were resolved and some of the inventive principles were in evidence. The second study generated many ideas using selected trends and inventive principles. Some of the ideas are found in recent designs but several were identified as genuinely new solution concepts. The third study showed how TRIZ tools can be applied at different system levels and showed the potential value of Ideal Final Result statements from TRIZ.

Marking the outcomes on the seven-point scale between incremental and radical was difficult. Solutions at the higher system level are easily marked as more radical. Solutions at the lower system levels may be radical in themselves and support step-change design, but it is nearly impossible to judge the extent to which they will improve the way the function is fulfilled. To some extent both the dishwasher study and the CHP study have confirmed the link between the system-level and the step-change criteria. Marking the seven-point scale was a matter of judgement and would be more robust with more judges and an inter-judge reliability assesment.

6.8 Summary and conclusions

This chapter set out to assess TRIZ's ability to contribute to eco-innovation through theoretical and practical studies. The overview of TRIZ tools, fundamental discoveries, and processes in section 6.1 gives an impression of the – sometimes overwhelming - diversity of TRIZ.

Some core theoretical aspects of TRIZ have been identified which inherently support eco-innovation: replacement of the design-by-compromise paradigm; avoiding trial-and-error problem-solving; the concept of ideal systems that deliver their function without cost or harm; and seeing waste as a resource awaiting a designed use within the system.

A study of the overlap between an eco-innovation tool and a TRIZ tool provided early ideas on adapting TRIZ for eco-innovation. However, later investigations showed that existing TRIZ tools need not be adapted, provided the designer includes environmental aspects in the system and attempts to solve problems high in the system hierarchy.

Three publications (Stevenson, Kogan & Kinnel, 1999; Low et al., 2000; Lamvik, 2001) were found in which the authors looked at particular parts of TRIZ for use in environmental design. All suggested that TRIZ for environmental design must focus on solving problems at the higher system levels.

Environmental design has not noticeably been taken up by the TRIZ research community. However, four TRIZ practitioners who had applied TRIZ in environmental projects were found and interviewed. Their deployment of TRIZ tools and outcomes from them varied; two projects resulted in changes implemented with immediate benefits and two projects resulted in paper designs for new system concepts. In all four projects the environmental drivers are linked to existing or impending legislation and all agreed that no special adaptation of TRIZ is needed to employ it in environmental projects.

From the experiences of TRIZ consultants introducing TRIZ into industry the following general conclusions were drawn:

- There may be barriers to TRIZ's take up due to time pressures, successful established tools and threats to designers' reputations.
- The most popular and flexible tools are the contradiction matrix, the inventive principles and the trends of evolution.
- TRIZ must be adapted to the existing way of working.

Finally, three worked examples were created to investigate the ability of TRIZ tools to contribute to eco-innovation *practice*. Particular tools were tried and the ideas outcome from them was examined using good-practice criteria distilled from previous chapters. One important conclusion from these worked examples was that: whereas the trends of evolution and inventive principles tend to contribute ideas at low levels of the system hierarchy, IFR statements were easily applied at different system levels.

From the theoretical and practical studies conducted in this chapter the following popular TRIZ tools were selected as potentially useful for eco-innovation: the contradiction matrix, the inventive principles, the trends of evolution, the separation principles and IFR statements. The next chapter investigates the potential for these tools to improve the early stages of eco-innovation and their use in team design practice. Simplified versions of these tools - to maintain 'momentum' in the creative session - were tested in an eco-innovation workshop.

Chapter 7 Testing Simplified TRIZ tools

The previous chapter identified the tools of interest to this thesis, this chapter reports on the experiment that was conducted to test these tools in an eco-innovation workshop. In particular, the potential of TRIZ tools to improve the early stages of eco-innovation and their use in team design practice was investigated.

Six multi-disciplinary teams were asked to: 'explore domestic dishwashing and generate solution concepts for environmental impact reduction'. Each team had a slightly different combination of TRIZ tools to use in their workshop. The outcomes from these workshops were judged by six environmental design experts with respect to criteria for good eco-innovation practice. These good-practice criteria were established to assess the outcomes from the worked examples presented in sections 6.7.2 and 6.7.3. of chapter 6.

The scores awarded by the judges provide the quantitative data for this study. These data were explored to compare the effects of the different experimental conditions and to look for trends in the criteria evaluated and other interesting findings. The qualitative data for this study were distilled from the transcripts of the all the teams' outputs recorded on paper. Conclusions are drawn on the outcome from the tools, the good-practice judging criteria and the experimental process in general.

7.1 Introduction

In chapter 5 it was established that to improve eco-innovation, a problem-solving tool is needed which can support: radical or step-change innovation; design at different system levels; and different types of design activities. TRIZ was identified as offering the most diverse tool set of the structured innovation methods reviewed. Chapter 5 also established that TRIZ may offer complimentary tools to the PIT diagram by helping to translate ideas from the enlarged solution space into more appropriate solutions that have the potential to be implemented.

Chapter 6 identified some core *theoretical* aspects of TRIZ which inherently support eco-innovation and from the *practical* studies conducted, the following popular TRIZ tools were selected as potentially useful for eco-innovation: the contradiction matrix, the inventive principles, the trends of evolution, the separation principles and IFR statements.

Chapter 6 also established that existing TRIZ tools need *not* be adapted provided the designer includes environmental aspects in the system and attempts to solve problems high in the system hierarchy. However, TRIZ tools must be adapted to the existing ways of working if they are to be introduced in industry. This thesis looks at workshops as the established way of getting different participants to work together at the early stages of eco-innovation. The TRIZ tools were therefore adapted for use in workshops; the tools had to be simplified in order to maintain 'momentum' in the session. Another benefit of simplifying the tools was to enable this experiment to be run using a self-briefing procedure. This means that the six teams received consistent written instructions describing the use of the tools and the experimenter could run the six workshops simultaneously.

7.2 Methods

The hypothesis investigated in this study is that use of the TRIZ tools will improve the outcomes from eco-innovation workshops. The use of the various TRIZ tools when compared with a placebo should result in the final concept being more original (H1), appropriate (H2), environmentally relevant (H3) and radical (H4). Furthermore, the final concept should display evidence of problem solving at higher system levels (H5). These hypotheses were tested with quantitative methods. The quantitative methods also look at the effects of the specific tools - IFR statements (A) and contradiction tools (B1 and B2) – on those dependent variables.

The quantitative analysis looks only at the final outcomes - the concepts defined by the teams - from the entire workshop sequence. The qualitative studies look at the output from the process and therefore say more about the effectiveness of each of the steps conducted and hence about the tools.

7.2.1 Participants

One of the concepts that needed to be tested was whether the tools would facilitate workshops with participants from different disciplines and backgrounds. In contrast to the PIT diagram experiment, the participants were from three distinct groups: final year students from an undergraduate course in industrial design; masters students from a masters course in design strategy and innovation; and finally post-graduates from various non-design-related disciplines. The participants were paid a small remuneration (£15) for their efforts. The payment made recruitment easier and strengthened the participants' commitment to show up on the day.

7.2.2 Experiment Design

This experiment is based on some of the experiences gained from the PIT diagram experiment and the criteria for good innovation practice distilled in section 6.7.

The previous experiment reported in chapter 4 showed that providing too many tools or tools that are too complex is likely to inhibit the effectiveness of the workshop. This chapter describes the testing of a number of TRIZ tools in a single workshop experiment, even though introducing several new methods is inherently problematic. The experiment was designed to balance the number of tools tried out and the complexity of those tools by simplifying the tools.

In the previous experiment most groups struggled with the time-keeping discipline for the session and there were too many instructions to be remembered by the participants throughout the session. In this experiment these problems were addressed by providing a step-by-step task booklet (master copy included as appendix 4). Several tools were tested in this sequential experiment, participants were not encouraged to read through the whole task booklet in advance, but to turn over the page upon completion of each task.

Conclusions from the previous experiment suggested that participants should be trained in the use of tools to ensure full understanding. This experiment tested several simplified tools, but it was considered that introducing several tools in one block would provide too much information to be remembered. Another option would be to have a method-coach in each of the rooms to control the session and introduce the tools at each stage. However, providing written instructions in the step-by-step task booklet was considered to be an effective way of conducting this experiment whilst contributing to the experimental control.

In the previous experiment there was excess time in the individual brainstorm part of the session which meant that unmanageable numbers of post-it notes were created. In this experiment the 'classic post-it note brainstorming' was used as the experimental control method at two stages. However, participants were not explicitly encouraged to produce a great quantity of ideas.

In the previous experiment there was a problem of reliability with the data recorded on paper by the groups. To provide more reliable data it was suggested that the data could be collected by trained observers or complete video recordings could be analysed. This experiment overcame this reliability problem in a less labour-intensive way (or a more efficient way) by providing special forms to capture output from the use of each tool (reduced sample copies of the forms are included in appendix 5). Extra stationery was provided and labelled by the participants according to the stage of the process they were working on. The forms and stationery allowed for a chronological transcription of all the data recorded on paper.

Independent variables

The aim of this experiment was to test the use of a number of TRIZ tools in an early stage eco-innovation workshop. The number of tools tested had to be limited and the following were selected: IFR statements, physical contradictions and technical contradictions. The groups looking at physical contradictions used the separation principles to generate solutions. The groups looking at technical contradictions used the contradiction matrix and the inventive principles to generate solutions.

The contradiction tools were thought suitable for a similar stage in the process. The experiment was designed to test the use of IFR together with either the physical or the technical contradictions. Table 7.1 shows how the factors were crossed, yielding the six experimental conditions.

	A		n- A	
B (1)	A/ B(1)	group 1	n-A / B(1)	group 2
B (2)	A/ B(2)	group 3	n-A / B(2)	group 4
n- B	A/ n-B	group 5	n-A / n-B	group 6
	A= ideal final result B(1)=Physical contradictions B(2)=Technical contradictions			

Table 7.1: Conditions allocated to the six groups

Dependent variables

For the quantitative study the final concepts that the teams described were judged according to the good-practice criteria established in section 6.7. These criteria form a measure of the tools' ability to contribute to the model for eco-innovation - presented in chapter 1 - by examining the final outcomes for originality, appropriateness, environmental relevance, radical-ness and evidence of problem solving at higher system levels. The criteria describe the attributes of successful outcomes from an eco-innovation workshop.

Exact definitions for those dependent variables are as follows:

- Original: the final concept is not seen in common current designs (H1).,
- Appropriate: the final concept could be taken up in existing industry (H2)
- Environmentally relevant: the final concept shows potential to reduce the environmental impact of dishwashing throughout its life cycle with or without possible rebound effects (H3).
- Radical: the final concept represents a step-change in the way the dishwashing function is fulfilled (H4).
- System level: the final concept displays evidence of problem solving at higher system levels (H5).

7.2.3 Procedure

Recruitment and Grouping

In contrast to the PIT diagram experiment in which uniformity of the teams was only tested in the warm-up part of the session, this experiment attempted to *proactively* create uniform teams of three, with one member from each of the different backgrounds. The participants were recruited by personal invitation. Part of the recruitment proceedure required participants to complete the eco-design test and Kirton's adaptor-innovator test. The outcomes from these tests (the KAI scores and eco-design scores) were used to allocate participants to teams. Descriptions of the tests are outlined below.

Cognitive styles are acknowledged as influencing the way participants tackle design problems and the way they work in teams (Pritchard & Stanton, 1999; Prather, 1994). One of the theories that can be used to define people's self-perceived cognitive styles is Kirton's Adaption-Innovation Inventory (KAI) (Kirton, 1977). Previous authors have used KAI scores to normalise the data from design research experiments (Snoek & Hekkert, 1998; Snoek, Christiaans & Hekkert, 1999). KAI-theory is compact and simpler than other theories. Belbin's theory, for example, allocates many more different profiles (Belbin, 1993). The KAI- test provides a simple score which was used as an indicator to compose more uniform teams for this experiment.

The participants were asked to fill in a Kirton adaption-innovation inventory response sheet which consists of 33 questions (Kirton, 1977). The response sheets were scored and one of the following three conditions were allocated to each participant: adopter (scores 60-90), in between (scores 90-110), and innovator (110-140).

Chapter 4 showed that providing environmental prompts did not offer any special advantage to the teams, as most had already been trained in Environmentally Sensitive Design. This experiment therefore assumes enough background knowledge in environmental design to set the task without special prompts or environmental design training sessions. Instead, the level of the participants' background knowledge of environmental design was assessed by conducting an eco-design test. The questions for the test were based on an interactive CD-rom by Philips Corporate Environmental & Energy Office (Philips, 1998).

The participants were asked to answer the ten multiple choice and true/false questions on the test sheet. The participants were given scores according to the number of correct answers. Subsequently, the average score for each of the groups - industrial designers, masters students and non-designers - was calculated and each participant was graded in their group as: above average, average or below average.

Table 7.2 shows the different types of participants, their KAI-scores and eco-design test scores. The participants were shuffled around this table to create reasonably uniform teams of three. Table 7.2 shows the grouping settled on, each column represents a group. Group 2 has a slightly different profile from the others as one of the recruited participants had to be substituted on the day. This new team member was an adopter instead of an innovator and his eco-design score was average instead of above average.

	group 1	group 2	group 3	group 4	group 5	group 6
tool used	A	n-A	A	n-A	A	n-A
tool used	B(1)	B(1)	B(2)	B(2)	n-B	n-B
name:	1a	2a	3a	4a	5a	6a
Ecodesign Q's	xxx	xx	xxx	Xx	xx	x
KAI-score	inno	adopt	inno	Betw	betw	betw
name:	1b	2b	3b	4b	5b	6b
Ecodesign Q's	x	xxx	xx	Xxx	xx	xx
KAI-score	inno	betw	betw	Inno	inno	inno
name:	1c	2c	3c	4c	5c	6c
Ecodesign Q's	xxx	x	xxx	Xx	xx	xx
KAI-score	betw	adopt	adopt	Adopt	adopt	inno
	xxx = above average in class xx = average x = below average					

Table 7.2: Teams created based on the participants' KAI-scores and eco-design scores

Communal briefing

The communal briefing in this experiment was minimal, as the experiment had been designed to run as a self-briefing procedure using task booklets. The first stage of the warm up session was introduced and conducted communally. Subsequently, the role of the task booklet, special forms and the intended labelling of the stationery were explained.

Warm up session

In the PIT diagram experiment, a warm-up session was used to check the uniformity of the random teams. This warm-up session looked at the design interest of the participants by asking them to select two pictures each that could represent their design interests, from a large bank of different magazines. The teams were asked to paste together their pictures as a picture board. The content of these boards was analysed and provided an indicator for the teams' design interests. The picture board exercise was also considered a successful warm-up exercise for the session. This was the main reason to conduct this session again.

Similar scoring categories were used for the analysis, which provides an extra indicator of the teams' uniformity. The pictures on the boards were counted and grouped in the following categories: nature (nature or natural products), society (social comment or human activity), architecture (atmospheric interior or interior design products), technology (cars, high-tech products or highly styled products) and other (classic products, or items with identities other than those defined above). Table 7.3 shows the outcomes from the analysis of these boards.

	nature	soc.	other	arch.	tech	total:
group 1	3	1	3	3	0	10
group 2	0	1	3	0	5	9
group 3	3	3	1	1	1	9
group 4	0	1	2	1	5	9
group 5	1	3	1	2	2	9
group 6	2	1	1	2	6	12

Table 7.3: Analysis of the content of the picture boards

The analysis of the boards showed a bigger discrepancy between the groups than in the PIT diagram experiment. The boards produced by group 2, 4 and 6 show stronger interests in high tech products, where group 1 and 3 collected most images of nature. An example of the differences in design interests can be seen on the boards produced by groups 1 and 6 (shown in figure 7.1).

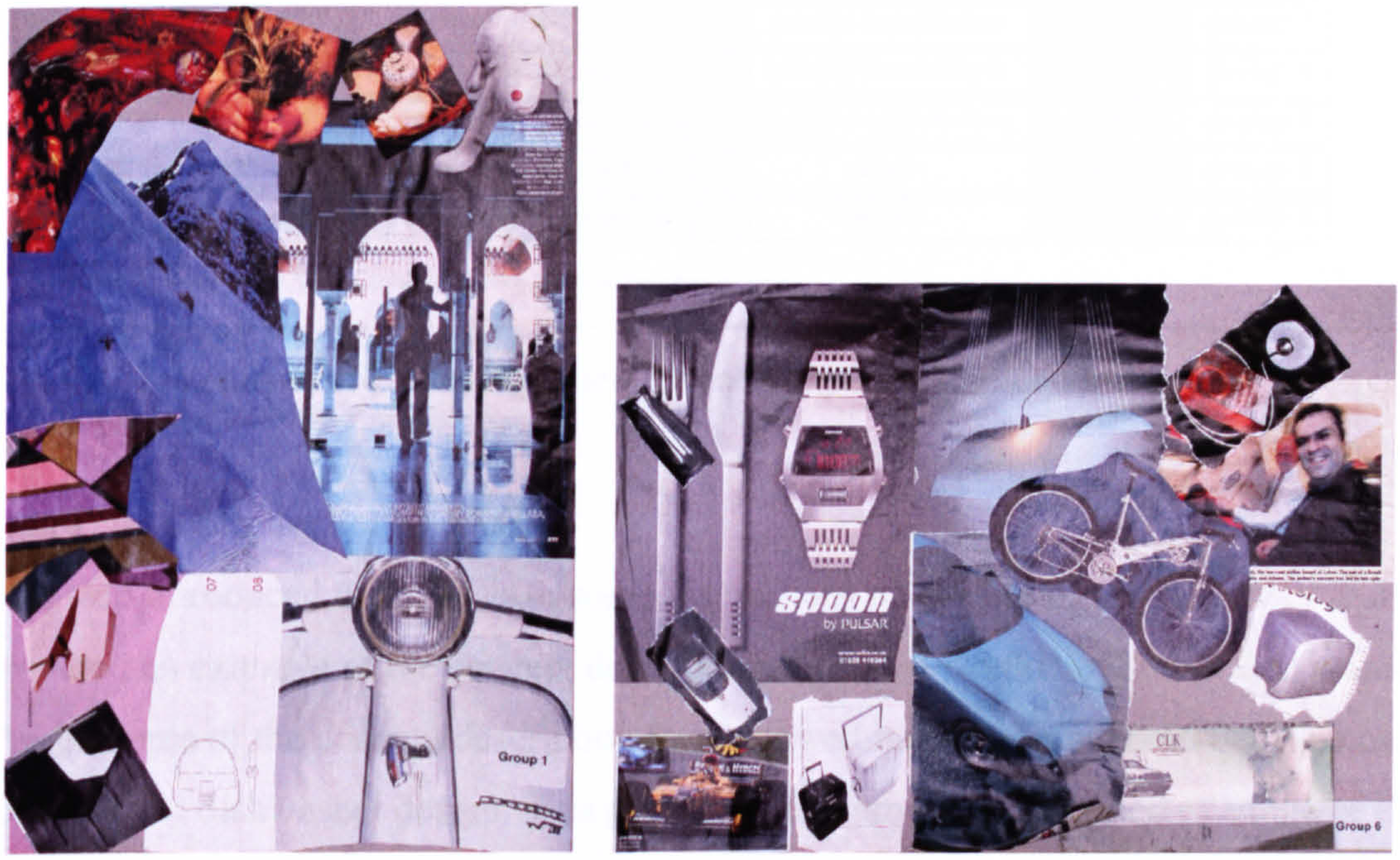


Figure 7.1: Picture boards group 1 and 6 next to each other

In this experiment a new element was added to the warm-up session. The teams were asked to brainstorm a name and company logo based on their picture board. This part of the warm-up did not form any part of the data. This easy warm-up exercise enabled the participants to begin to get to know each other and start working together.

The seven step-process and task booklet

As described in section 7.2.2, providing the written task booklet was intended to: overcome time-keeping problems; help the participants deal with number of instructions to be remembered by introducing them sequentially; and contribute to the consistency of the experimental conditions between groups. The overview in figure 7.2 shows the sequence that was designed for each experimental condition and each step is described and explained in the following section. A master copy of the task booklet is included in appendix 4.

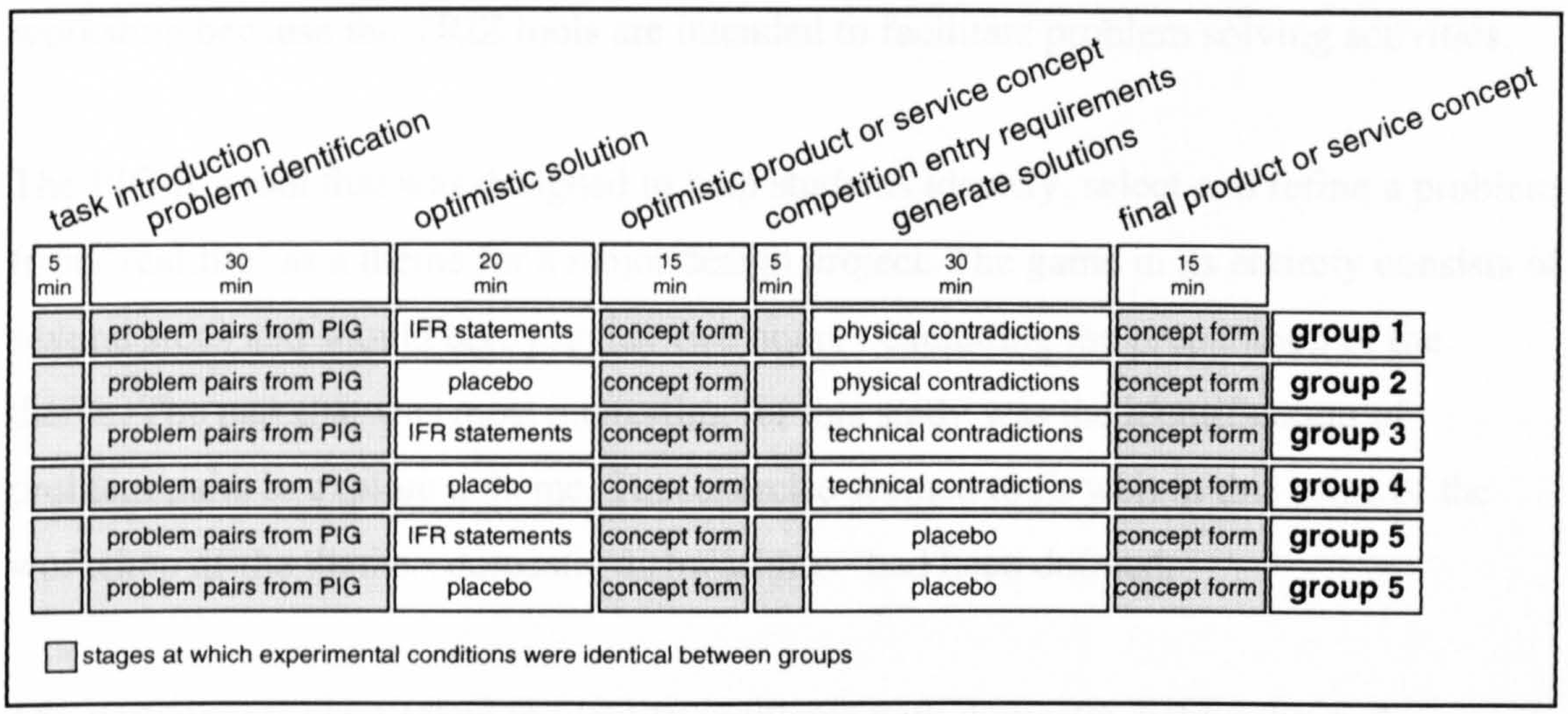


Figure 7.2: Sequence of steps designed for each experimental condition

Step 1: task introduction (5 min.)

This step introduced the task, gave some instructions on the use of the stationery and provided an example of the concept description form that would be used in step 4 and 7. The example of the concept description form showed how the form could be filled out for a current dishwasher design. This provided the teams with a worked example of the use of the form as well as a lot of information on current state-of-the-art dishwashers.

The task was worded as follows: ‘Explore domestic dishwashing and generate solution concepts for environmental impact reduction. These solution concepts might be new product or service concepts which either replace the current product model or which change the users’ behaviour’. The wording was carefully selected:

- to promote consideration of the way the function is fulfilled;
- to encourage consideration of the dishwashing system at higher levels;
- to shift the focus from ‘dishwasher’ to ‘dishwashing’ (activity-centred).

Step 2: problem identification (30 min.)

This part of the session was taken from the Problem Identification Game (PIG) (Jacques & Talbot, 1975). It was intended as a simple warm up *tool* for all the groups; the output was not intended to provide specific data. This tool was employed to acquaint the teams with tool instructions and forms. Another reason for including this problem identification stage was to provide a focus on problem solving for the rest of the workshop because the TRIZ tools are intended to facilitate problem solving activities.

The PIG is a tool that was designed to help students identify, select and refine a problem from 'real life' as a theme for a major design project. The game in its entirety consists of several steps and should take roughly two hours - excluding the preparation of the theme. The part that was most interesting for this study was the identification of problem pairs to explore a theme. This exercise seemed to fit well in this stage of the workshop as the theme - domestic dishwashing - had been defined.

The participants were asked to identify problems with domestic dishwashing. A dishwashing booklet was provided to help broaden the range of cultural, social and practical themes considered. The teams were asked to select an interesting problem theme to explore which was distilled into a problem pair. Other problem pairs were then created using some of the stimuli from the PIG: antithesis, abolition, example and anagram.

Step 3: Optimistic Solution (20 min.)

Having explored problem themes, the teams were asked to project optimistic solutions for the future of domestic dishwashing. Half the teams (groups 1, 3, 5) were using the Ideal Final Result (IFR) statements; the other teams (groups 2, 4, 6) were using no method (classic post-it note brainstorming).

The IFR statements have been distilled from the TRIZ's ideality concept. An example of a similar version to that used in this experiment can be found as part of the creaTRIZ software (Creax, 2001). The tool is intended for problem exploration but assists participants in generating radical new solution directions. This tool is similar to an existing workshop technique called 'back-casting' but is more problem-focused.

First, the participants describe the Ideal Final Result (IFR): a system that fulfils all functions required without any impacts. They do this by describing the functions desired and the impacts to be eliminated. From the IFR the teams are asked to generate intermediate optimistic solutions towards today's solution. The exact instructions provided can be viewed in appendix 4. The groups without the tool were asked to explore some optimistic solutions and were given instructions for 'classical brainstorming' similar to those given in the PIT diagram experiment.

Step 4: Optimistic Product or Service Concept (15 min.)

This stage was the half-way point where all teams were asked to define their initial optimistic product or service concept based on their developments in step 3. The output at this stage was intended to provide data on the effect of the IFR statements. The teams were provided with the concept description form, which can be viewed in appendix 4. The boxes on the form were designed to ensure a similar level of definition between the groups. The forms make the output quality from the teams more uniform and easier to judge for analysis. They were asked to capture as much detail as possible.

Step 5: Competition Entry requirements (5 min.)

All teams were briefed to generate a final product or service concept (in step 7) for domestic dishwashing to be entered in a 'sustainable design competition'. Introducing the competition entry requirements provided more constraints and was intended to stimulate the participants to look into their concept in more detail and transform it into a more appropriate solution. Competition entries have been used to focus workshops by authors before (Sherwin, 2000; Valkenburg, 2000).

In this experiment the competition was fictional. The teams were given the criteria to consider for their competition entry (see appendix 4). These criteria were developed based on the competition entry details for the 'design sense awards' a competition run in 2001 by the design museum in London.

Step 6: Generate Solutions (30 min.)

Having defined their initial optimistic product or service concept (step 4) the teams were asked to develop their concepts in more detail. All teams were asked to identify the main issues they wanted to tackle for their competition entry. At this stage in the process, the teams were in three different experimental conditions: two teams (groups 1 and 2) were using the physical contradiction from TRIZ, two teams (groups 3 and 4) were using the technical contradictions from TRIZ, the other teams (groups 5 and 6) were using no method (classic post-it note brainstorming method).

Both the contradiction tools were introduced at this late stage because they are thought to be most useful when solving specific problems in fairly well-defined concepts or products (systems). Both the tools were simplified, and step-by-step instructions and forms were designed to support each step (appendix 4).

The physical contradictions were introduced by providing three examples on a sample form. The teams were asked to translate the issues they wanted to tackle for the competition entry into physical contradictions. They were then asked to generate and record new solution ideas by using the separation principles to resolve contradictory requirements in time, space or parts.

The technical contradictions were introduced by describing them as engineering "trade-offs" and providing a complete worked example on a sample form. First, they were asked to define the issues they wanted to tackle for the competition entry as technical contradictions and then translate them into improving features and worsening features provided on the axes of the contradiction matrix. The matrix was used to identify the inventive principles associated with their contradiction and a 40-principles booklet (Altshuller & Shulyak, 1997) was used to generate new solution ideas.

Step 7: Final Product or Service Concept (15 min.)
At this stage all teams were asked to define their final product or service concept for their competition entry based on their developments in step 6. The output at this stage was intended to provide data on the effect of the contradiction tools. All teams were provided with the same concept description form used in step 4.

Asking for concept output at different stages in experimental workshops has been done by other authors to assess the effects of the variables introduced through the process. For example, Snoek, Christiaans and Hekkert (1999) viewed their experiment as a process and asked for output at several stages during their workshop. Three different outputs were marked by their judges: problem conception 1, problem conception 2 and final design concepts.

Debriefing

The debrief period at the end of the workshop consisted of checking the written materials handed in and asking participants whether there had been any major problems with the workshop sequence.

7.2.4 Equipment

All groups had the following equipment: post-it notes, pens, felt tip pens, pencils, some coloured paper and glue. All groups had the following papers: the task booklet adjusted to the condition of each group, special forms to capture output from the use of each tool, extra stationery with group and stage labels (A4 and A3 sheets and envelopes), the dishwashing booklet. The teams trying out the technical contradictions (groups 3 and 4) also had an A2 sized copy of the contradiction matrix and an inventive principles booklet.

7.2.5 Data reduction and coding

Quantitative data

First, all the paper outcomes from the workshop teams were transcribed. Then, to make the final concepts consistent and manageable for judging by external experts this information was distilled into a standard format. The concept description forms provided at step 4 and step 7 were designed to provide direct output for judging, however, due to a problem with experiment design described in section 7.3 the final output had to be distilled from the entire transcripts.

Similar manipulation of the workshop output has been done by other design researchers. Dorst and Cross (2001) for example, recruited nine practising designers to take part in a 2.5 h. design workshop. The outcomes from the workshop were redrawn and presented in a consistent format in order to eliminate the effects of the quality of the presentations. The concepts were then assessed by five judges by showing slides of the redrawn concepts with one-sentence summaries in random order for 15 seconds to create an overall impression of the outcomes. Then one of the judging categories would be introduced, the slides were shown again for 15 s. in random order, and judges had to score that category. Each category was marked out of 10 in this way. Redrawing the concepts, and employing a controlled judging process, improves on the reliability of the results from marked materials.

In the experiment reported here each team's output was given on two PowerPoint slides. Two sketches were selected from the paper output –not redrawn- and the concept was summarised in one sentence. Three or four of the most important issues that the team had concentrated on were listed. Four or five of the final concepts features were listed. The six concepts were put together as a short PowerPoint presentation. Figure 7.3 below shows the PowerPoint slides presented to the judges.

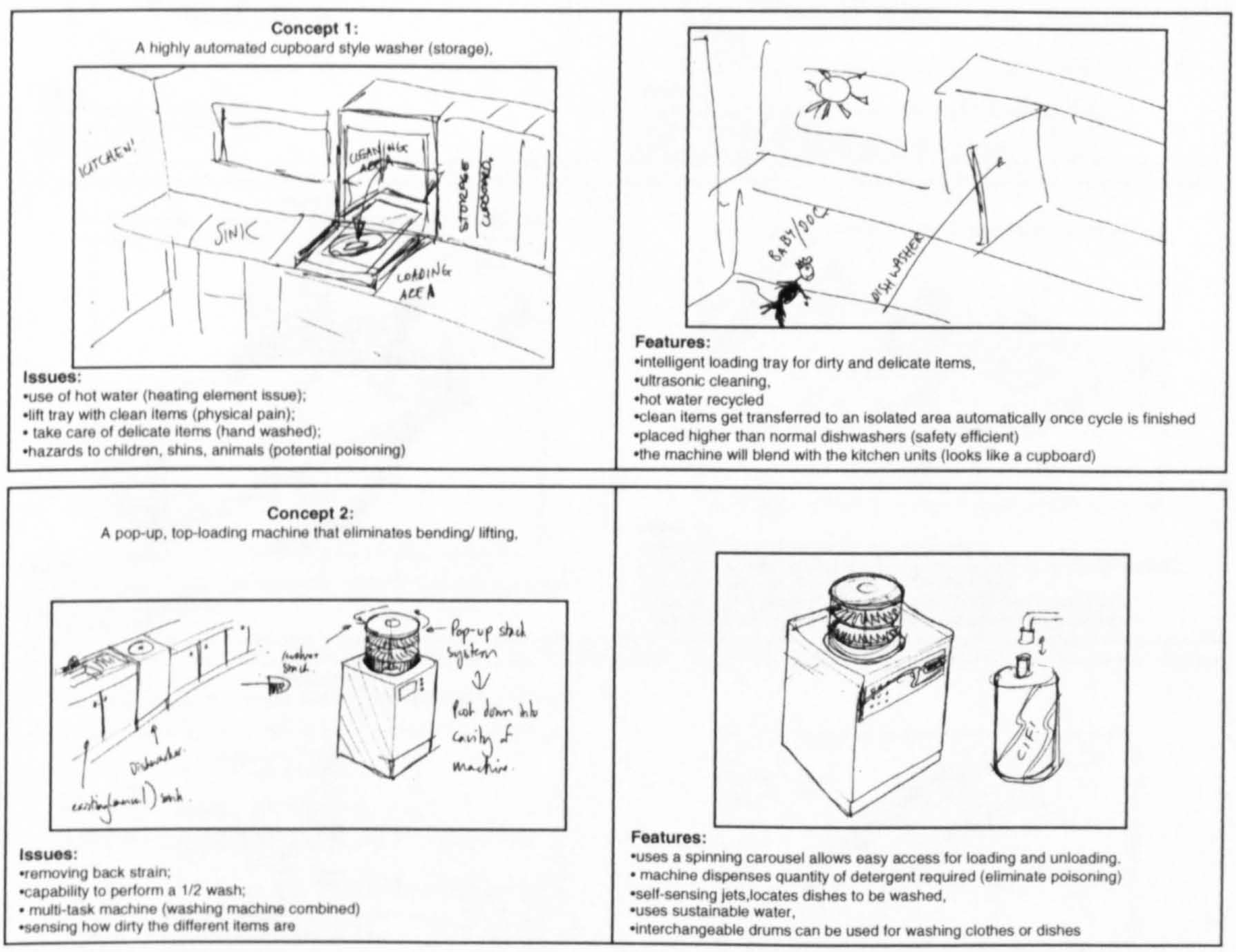
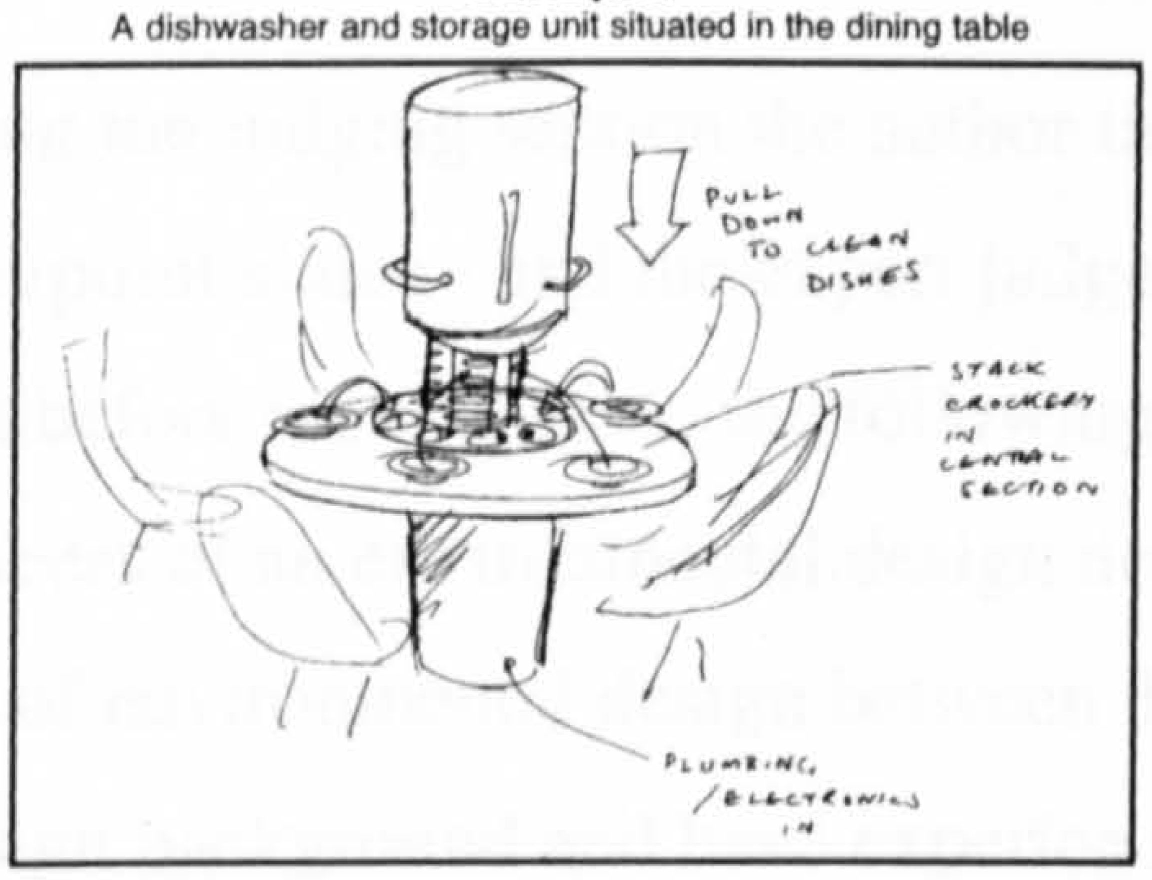
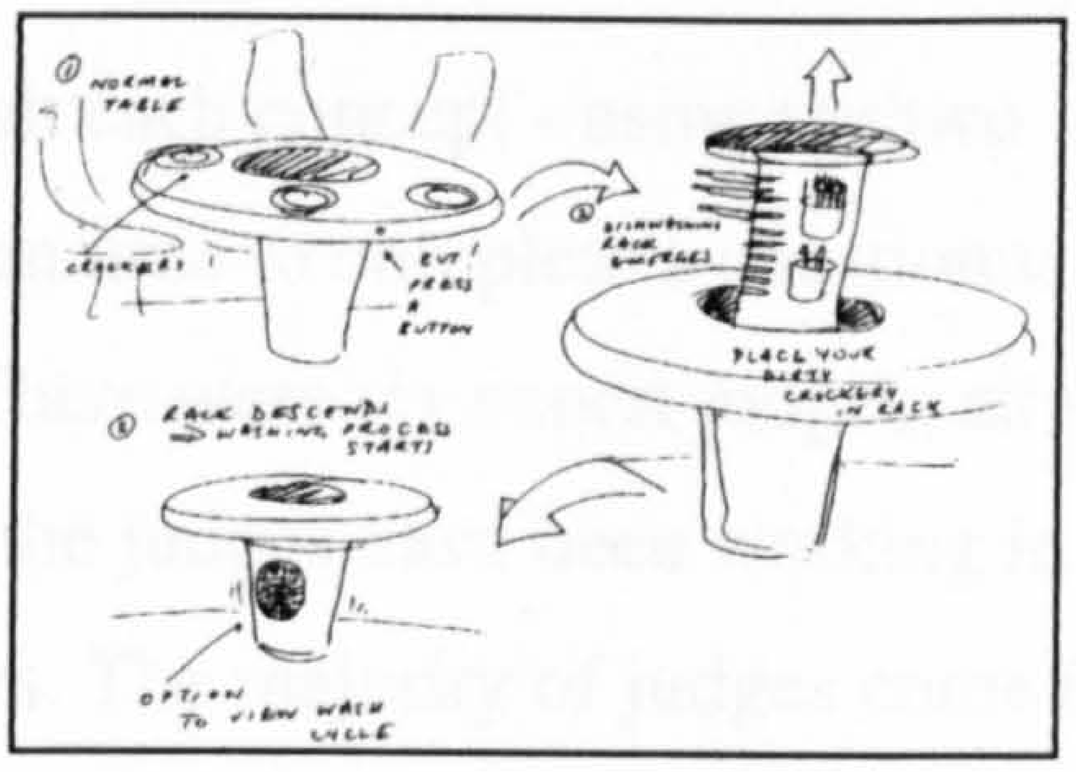


Figure 7.3: PowerPoint slides presented to the judges

Concept 3:
A dishwasher and storage unit situated in the dining table

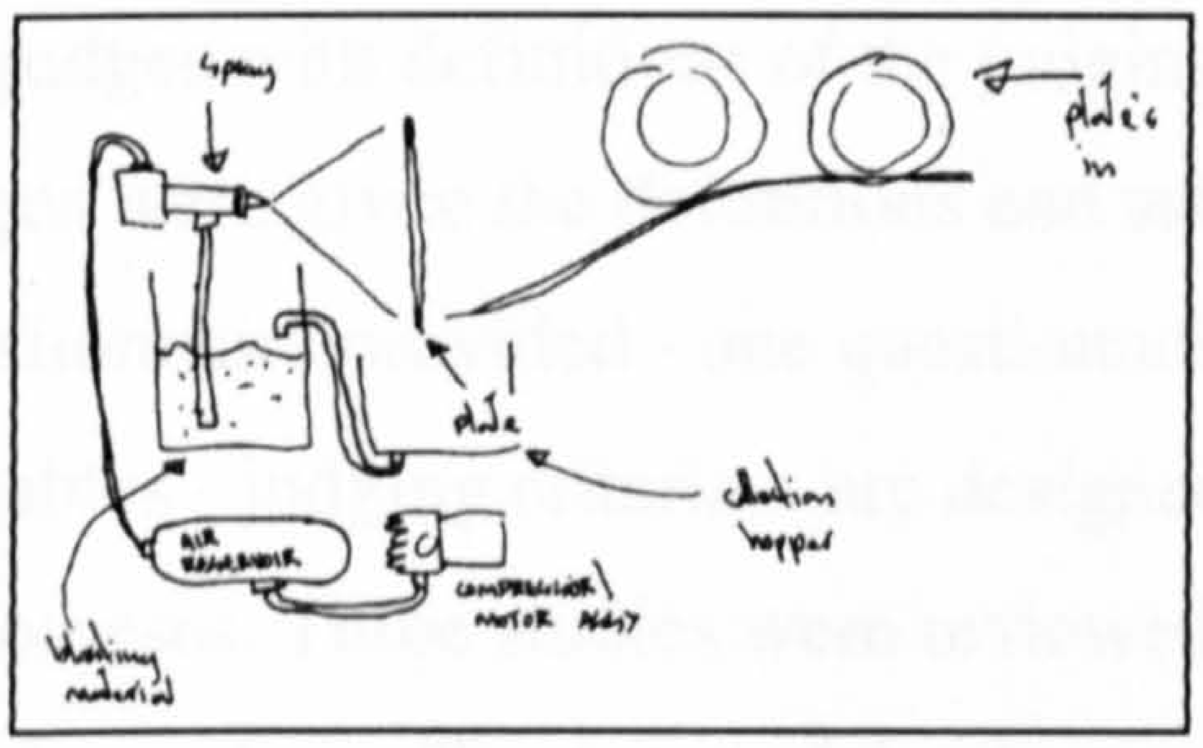


Issues: user interface and ease of use,
questionable labour saving benefit of dishwashers
Pre- and post-wash routine chores

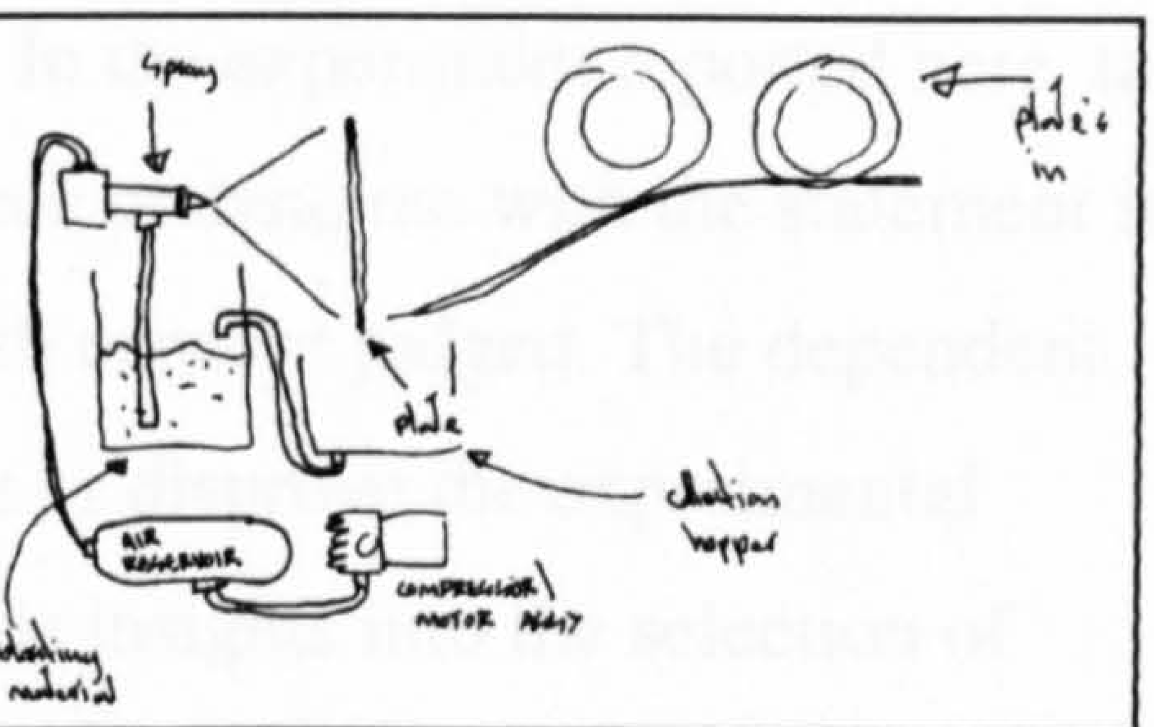


Features:
•self-contained, crockery washing, drying and storage device built into the eating area
•Interactive LCD touch screen to specify type and no. of items,
•intelligent dosing and cycle time
•provides continuous feedback throughout cycle (option to view the process)

Concept 4:
New dishwasher technology and plates based on 'post-it note plates' and 'sand blasting'

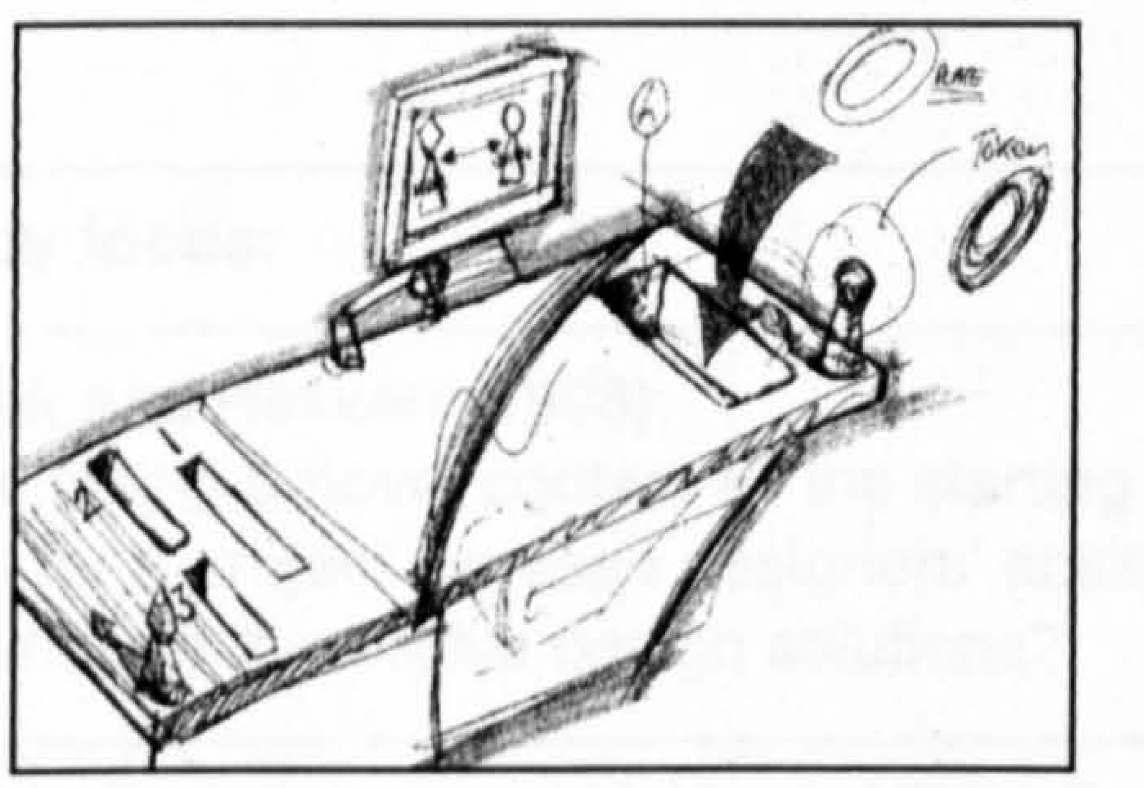


Issues:
•dishwashers use too much water
•washing liquids and powders used
•germs and hygiene

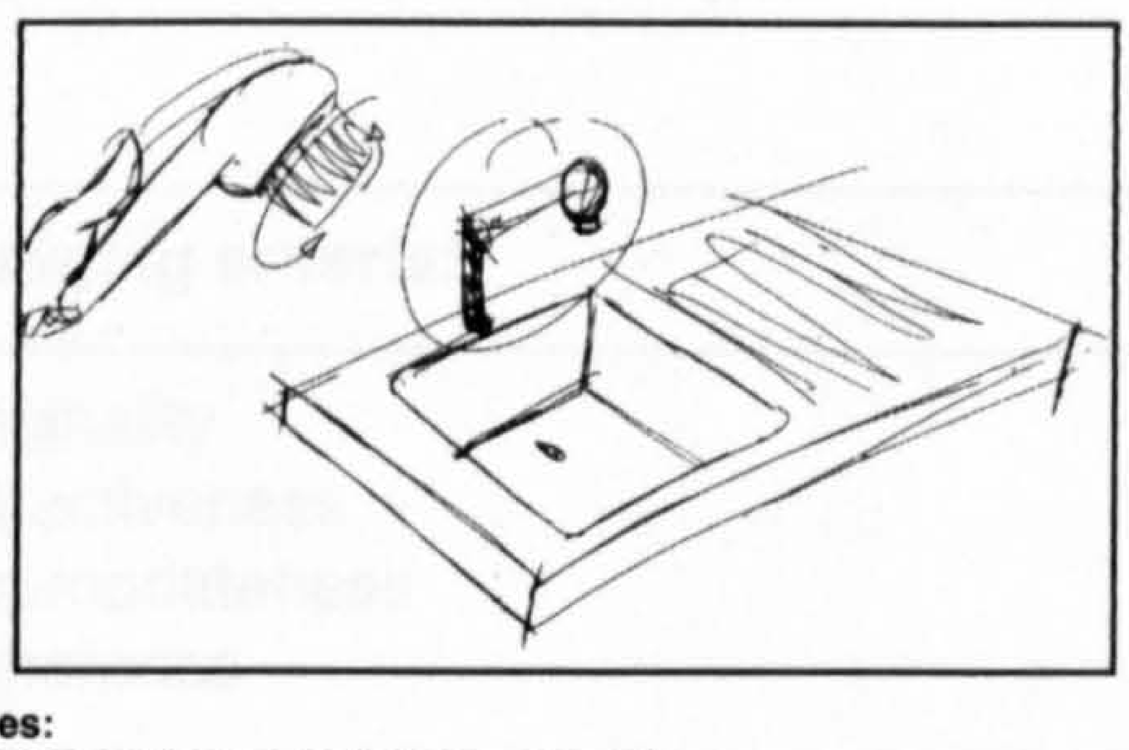


Features:
• compressed air dishwasher, using Post-it surface deposition plates
•endless supply of new plates
•CD tray feed, manual feed, low-tech intuitive interface

Concept 5:
A continual input - output washer where the output is a 'surprise' game.

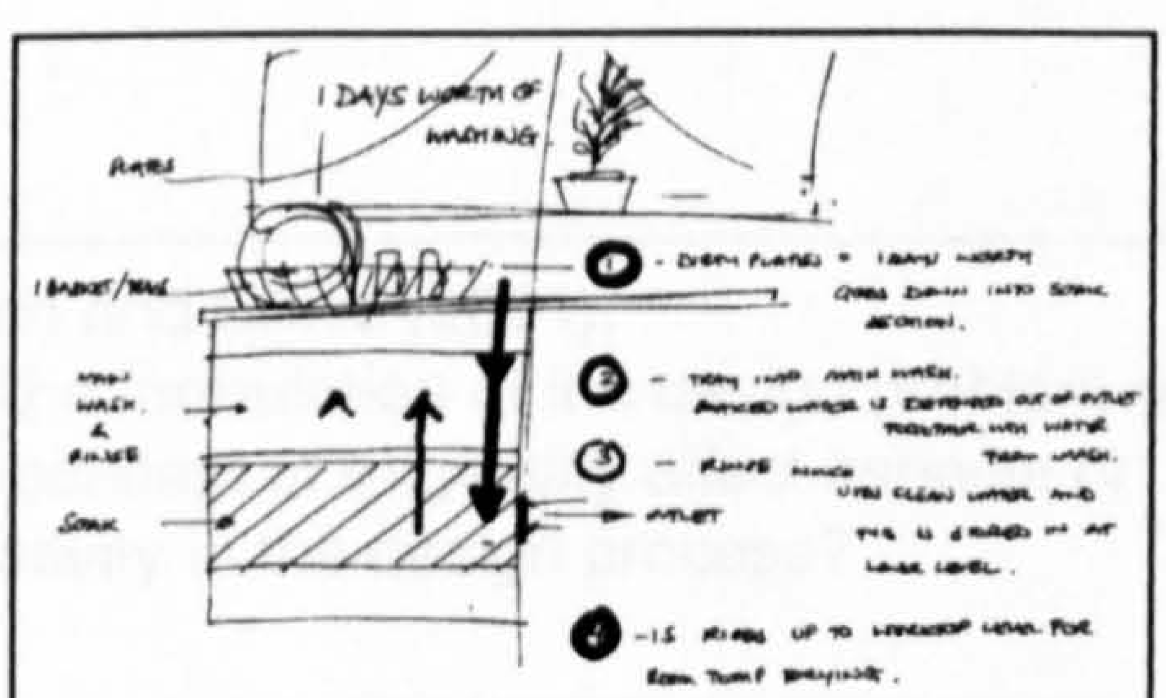


Issues:
social (family) issues: automatic dishwashing effects family traditions and rituals
drying energy of dishwashers
pre- washing of crockery

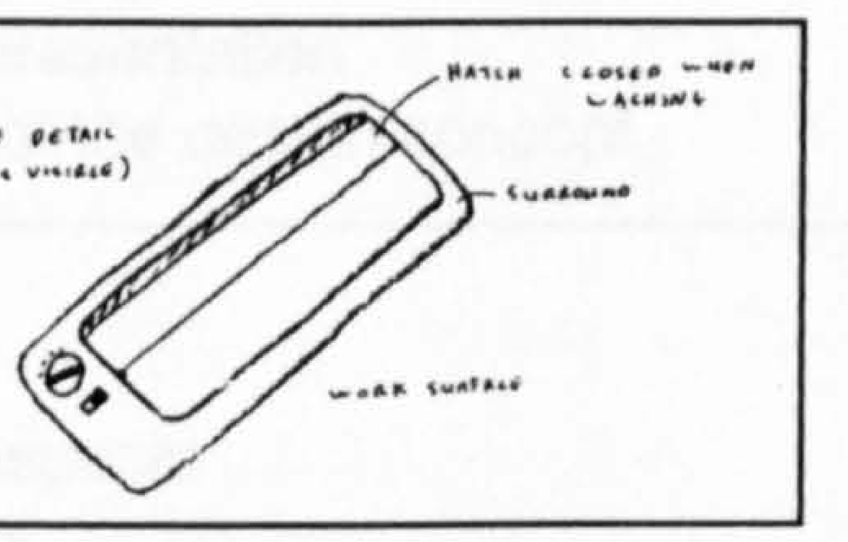


Features:
•big LCD screen interface for the 'game element'
•Drying game: tokens register users, dirty plate inserted, automatically washed, pops out of other slot for dryer to guess, manual drying
•continual input - output: don't have to wait for a large load to accumulate
• integrated tap with expendable hose with rotating brush for other items.

Concept 6:
Long soaking washer which takes a basket of washing through the countertop



Issues:
water efficiency: rinsing dishes or soaking before filling the machine
ergonomics: stacking and bending,
smaller households,



Features:
•Basket lowered through hatch from above, hatch closed when washing, controls on counter top
•Soaks the dishes (immersed) at base of the machine, subsequent cycle is short
•dishes are returned to the counter to dry at room temp
•Basket takes one days worth of items to prevent grime drying up
•Rinse water is kept and used as soaking water for next wash

Figure 7.3 continued: PowerPoint slides presented to the judges.

During the judging session the author talked through each concept - using the two powerpoint slides - and the expert judges were given time to complete a questionnaire sheet before moving on to the following concept. There were six expert judges; all were members of an environmental design network. All the judges have been working in the field of environmental design between 3 and 8 years. The majority of judges come from a design background and have experience marking student design work.

Previous authors have improved the judging procedures of design concepts by providing the judges with definitions of the judging criteria. In the experiment reported here, the judges were given the definitions and asked to agree or disagree with the statement in a questionnaire provided - one questionnaire for each concept judged. The dependent variables - judging criteria – are designed to prove or disprove the experimental hypotheses. Three studies were reviewed to provide insights into the selection of judging criteria. The focus of the three studies reviewed and the criteria selected for judging are shown in table 7.4 below. There were two ways of marking employed in these studies: seven-point bi-polar scales and simple numerical marking out of ten.

Study focus:	**Judging criteria:**
Snoek and Hekkert (1998): Does taking a novel context as the starting point for a project increase designers' ability to generate innovative design solutions?	originality attractiveness appropriateness coherence
Snoek, Christiaans and Hekkert (1999): Does the type of information provided as the starting point for a project affect the creativity of the design solutions?	originality potential for leading to a good solution distance from the actual problem atypicality realisability quality of presentation final mark of the design concept
Dorst and Cross (2001): Do the formulation of the design problem and the concept of originality affect aspects of creativity in the design process?	creativity aesthetics technical aspects ergonomics business aspects total judgement

Table 7.4: Focus of the three studies reviewed and the criteria selected for judging

This chapter looks at whether the TRIZ tools selected improve the early stages of eco-innovation practice. The judging criteria selected could therefore be based on the criteria for good eco-innovation practice distilled in section 6.7. Table 7.4 confirms that the criteria developed in section 6.7 are similar and are likely to provide a similar types of data. A copy of the questionnaire is included in appendix 6. The questionnaire was designed as follows:

Originality:
The judges had to consider the following statement: 'The concept is not seen in current versions' and mark the concept on a four-point ordinal (ranking) scale as: Definitely Not, Probably Not, Probably Yes or Definitely Yes.

Appropriateness:
The judges had to consider the following statement: 'The concept could be taken up in existing industry' and mark the concept on a four-point ordinal (ranking) scale as: Definitely Not, Probably Not, Probably Yes or Definitely Yes.

Environmental relevance:
The judges had to consider the following statement: 'The concept shows potential to reduce the environmental impact of dishwashing' and mark the concept on a four-point ordinal (ranking) scale as: Definitely Not, Probably Not, Probably Yes or Definitely Yes.

Radicalness:
The judges had to consider whether the concept generated was incremental or radical. They had to mark the concept on a seven-point ordinal (ranking) scale where one extremity had been labelled 'incremental' and the other 'radical'. Incremental was defined on the questionnaire as 'small improvement or re-design of existing dishwasher' and radical was defined as 'a step-change in the way the dishwashing function is fulfilled'.

System levels:

The judges had to consider at what level the concept generated changes in dishwashing. They had to mark the concept as one of three categories: sub-system, system or super-system. The sub-system level was defined as new elements or parts of an existing dishwashing device. The system level was defined as a new type of dishwashing device. The super-system level was defined as a different way of domestic dishwashing.

The criteria originality, appropriateness, environmental relevance and radicalness all provided ordinal data, whereas the system level data was categorical.

Qualitative data

The qualitative data is from two sources: observations made by the author from the workshop transcriptions; and the comments made by the judges on their questionnaire. The transcriptions provided insights into the actual process the teams moved through and where they deviated from the seven-step process. This qualitative data identifies problems with the experiment design and subsequent validity of some of the quantitative data. The second part of the qualitative data is from the questionnaire sheets, which included two spaces for judges to comment on the strengths and weaknesses of the concepts. This data provides some insights into the aspects that these environmental experts considered important when assessing the concepts.

7.3 Results

From the first look at the transcripts a major problem with the experiment design was identified at step 7. The researcher intended to look at the differences between the concept description forms at step 4 and the concept description forms at step 7. The differences between the two concept descriptions would say something about the contradiction tools (B1 and B2) tried out in step 6. However, most teams did not complete step 7; they may have run out of time or commitment. Groups 1 and 2 were the only teams to use the final description form, but neither group had generated any new ideas in step 6. Their final description forms recorded incremental changes to the design they had described in step 4.

This problem with the experiment design meant that analysis of the tools tested in step 6 is very difficult. To make the most of the experimental data, the final concepts to be judged were distilled from each team's entire transcript. The quantitative data in this experiment therefore reflects the final outcomes from the teams using different combinations of tools. The quantitative data does not reflect the sequential information and therefore does not allow very strong conclusions about the specific tools.

7.3.1 Quantitative Data

First, a Kruskal-Wallis one-way analysis of variance was performed on the ordinal data to test whether there were statistically significant differences between the experimental conditions (groups). If a difference was found then Mann-Whitney U pair-wise comparisons were conducted to test for statistically significant differences between each pair of groups in turn. A chi-square test would normally also have been performed for the categorical data (system levels). However, this data was too sparsely populated – an expected frequency count less than 5 in most cells - which means this data can only be reported in a descriptive way.

A second set of statistical checks was performed to look for any specific effects from the use of the IFR statements (A) and the contradiction tools (B1 and B2). A Kruskal-Wallis one-way analysis of variance was performed on the ordinal data to determine if there was a statistical significance between the different tools used. If a difference was found then Mann-Whitney U pair-wise comparisons were conducted to test for the statistical significance of the differences between tools.

The following section looks at each part of the main hypothesis in turn and the effects of both tool types in turn. The full analysis of the quantitative data is included in appendix 7.

Final concepts, judged on originality (H1)

Kruskal-Wallis one-way analysis of variance between groups showed that the observed frequencies differed significantly from the expected values ($\chi^2_5 = 11.08$, $p<0.05$). This means that the originality was affected by the independent variables. The pair-wise comparison shown in table 7.5 shows that there are statistically significant differences between group 6 and the groups 4 and 5 respectively.

	group 1	group 2	group 3	group 4	group 5	group 6
group 1		Ns	ns	ns	ns	ns
group 2			ns	ns	ns	ns
group 3				ns	ns	ns
group 4					ns	*
group 5						*
group 6						

ns = not statistically significant
* = $p<0.05$ ** = $p<0.01$ *** = $p<0.001$

Table 7.5: Pair-wise comparisons between groups for statistical significance of originality scores

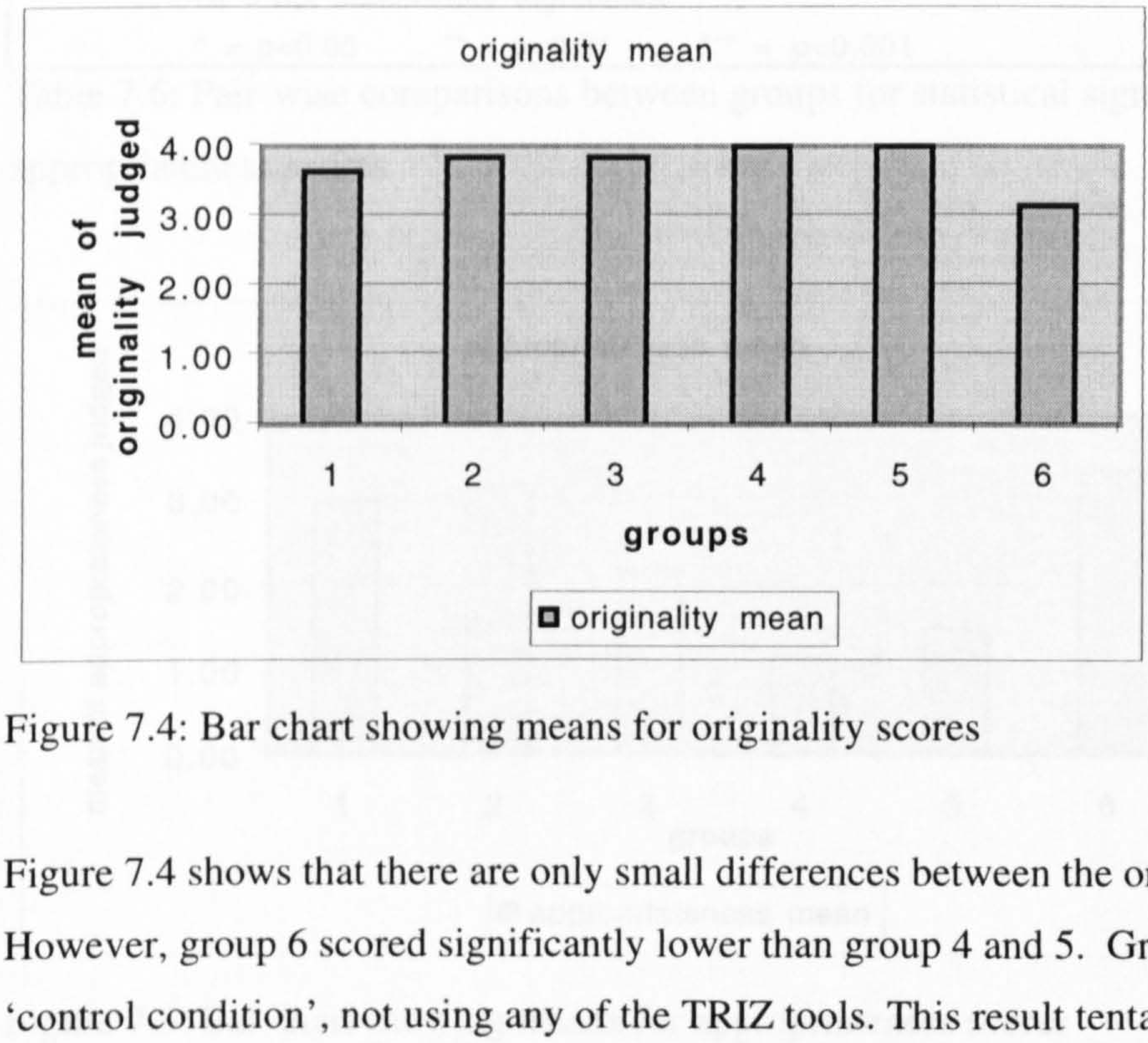


Figure 7.4: Bar chart showing means for originality scores

Figure 7.4 shows that there are only small differences between the originality scores. However, group 6 scored significantly lower than group 4 and 5. Group 6 was in the 'control condition', not using any of the TRIZ tools. This result tentatively suggests that using *some* tools in design teams is beneficial when step-change results are sought. This finding suggests that providing a tool or method of some sort makes the session more constructive.

Final concepts, judged on appropriateness (H2)

Kruskal-Wallis one-way analysis of variance between groups showed that the observed frequencies differed significantly from the expected values (χ^2_5= 25.82, p<0.01). This means that the appropriateness was affected by the independent variables. The pair-wise comparison shown in table 7.6 shows that there is a statistically significant difference between many of the groups.

	group 1	group 2	group 3	group 4	group 5	group 6
group 1		Ns	*	* *	* *	ns
group 2			*	* *	* *	ns
group 3				*	ns	*
group 4					ns	* *
group 5						* *
group 6						

ns = not statistically significant
* = p<0.05 ** = p<0.01 *** = p<0.001

Table 7.6: Pair-wise comparisons between groups for statistical significance of appropriateness scores

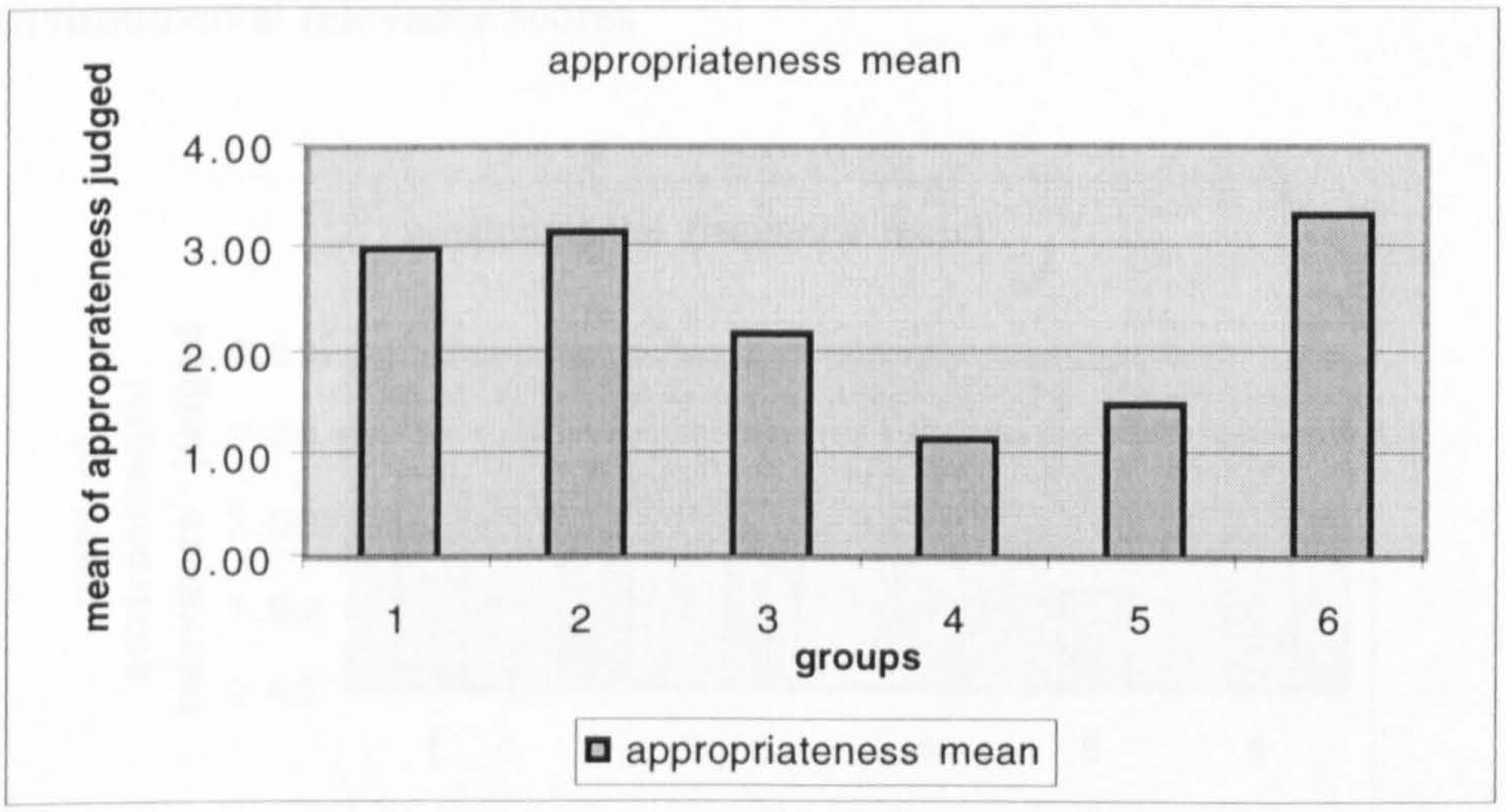


Figure 7.5: Bar chart showing means for appropriateness scores

Figure 7.5 shows that groups 1, 2 and 6 scored high whilst groups 4 and 5 scored low. Looking at the different conditions however, there does not seem to be an obvious pattern associated with the different tools. The second set of statistical checks will look more specifically for patterns associated with the different tools.

Final concepts, judged on environmental relevance (H3)

Kruskal-Wallis one-way analysis of variance between groups showed that the observed frequencies differed significantly from the expected values ($\chi^2_5 = 17.56$, $p<0.01$). This means that the environmentally relevance was affected by the independent variables. The pair-wise comparisons shown in table 7.7 show that there are statistically significant differences between group 5 and groups 1, 2, 3 and 6 respectively. Also statistically significant differences were found between group 6 and group 3.

	group 1	group 2	group 3	group 4	group 5	group 6
group 1		ns	Ns	ns	**	ns
group 2			Ns	ns	**	ns
group 3				ns	*	*
group 4					ns	ns
group 5						**
group 6						

ns = not statistically significant
* = p<0.05 ** = p<0.01 *** = p<0.001

Table 7.7: Pair-wise comparisons between groups for statistical significance of environmental relevance scores

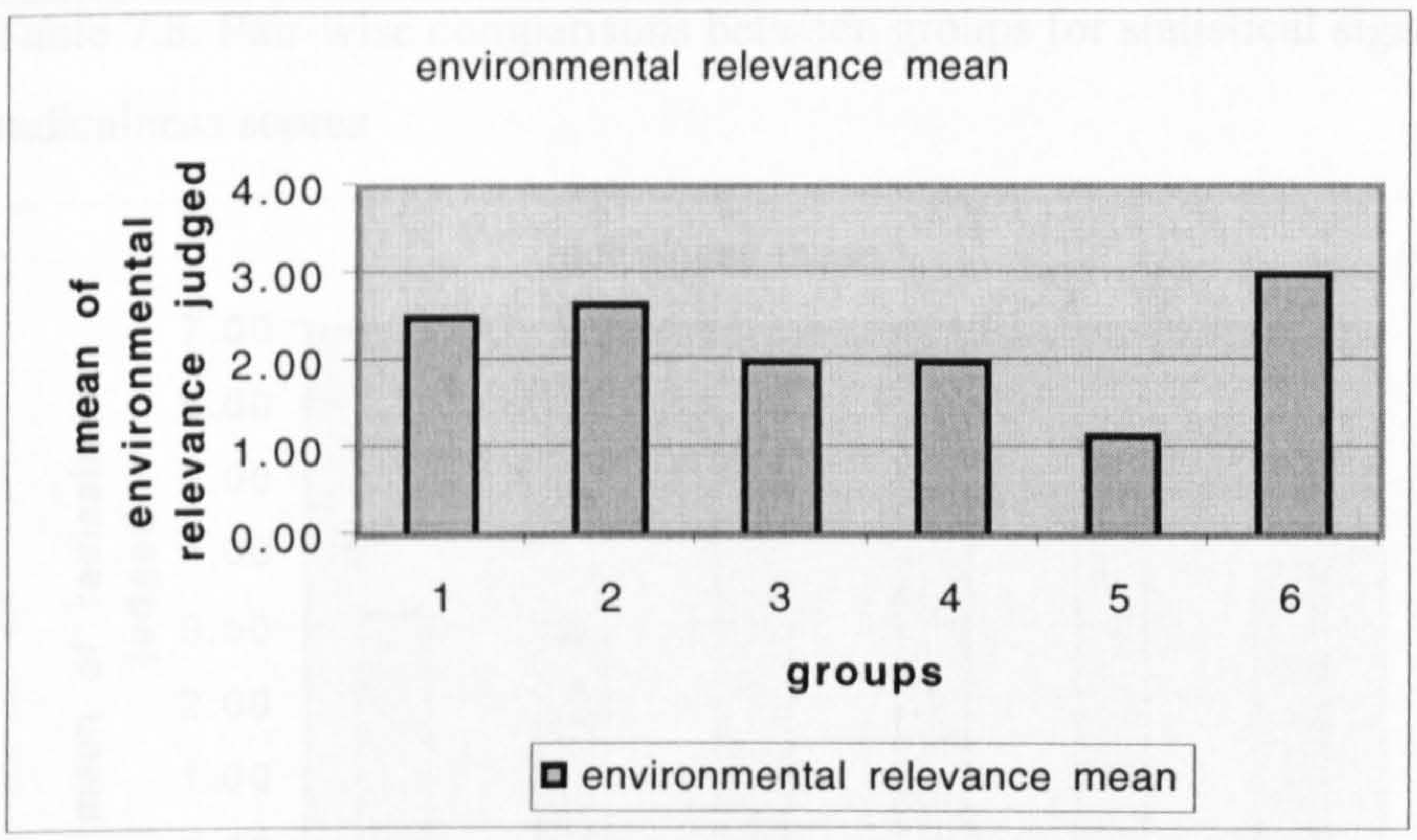


Figure 7.6: Bar chart showing means for environmental relevance scores

Figure 7.6 shows that *again* groups 1, 2 and 6 scored high whilst group 5 scored particularly low. The similarity of the patterns found in figures 7.5 and 7.6 indicates that there may be a link between appropriateness and environmental relevance scores.

Final concepts, judged on radicalness (H4)

Kruskal-Wallis one-way analysis of variance between groups showed that the observed frequencies differed significantly from the expected values ($\chi^2_5 = 20.39$, $p<0.01$). This meant that the radicalness was affected by the independent variables. The pair-wise comparison shown in table 7.8 shows that there is a statistically significant difference between group 4 and *all* other groups ($0.0028 < p < 0.0419$) and between groups 1, 2 and 6 and group 3.

	group 1	group 2	group 3	group 4	group 5	group 6
group 1		ns	**	**	ns	ns
group 2			*	**	ns	ns
group 3				*	ns	*
group 4					*	**
group 5						ns
group 6						

ns = not statistically significant
* = p<0.05 ** = p<0.01 *** = p<0.001

Table 7.8: Pair-wise comparisons between groups for statistical significance of radicalness scores

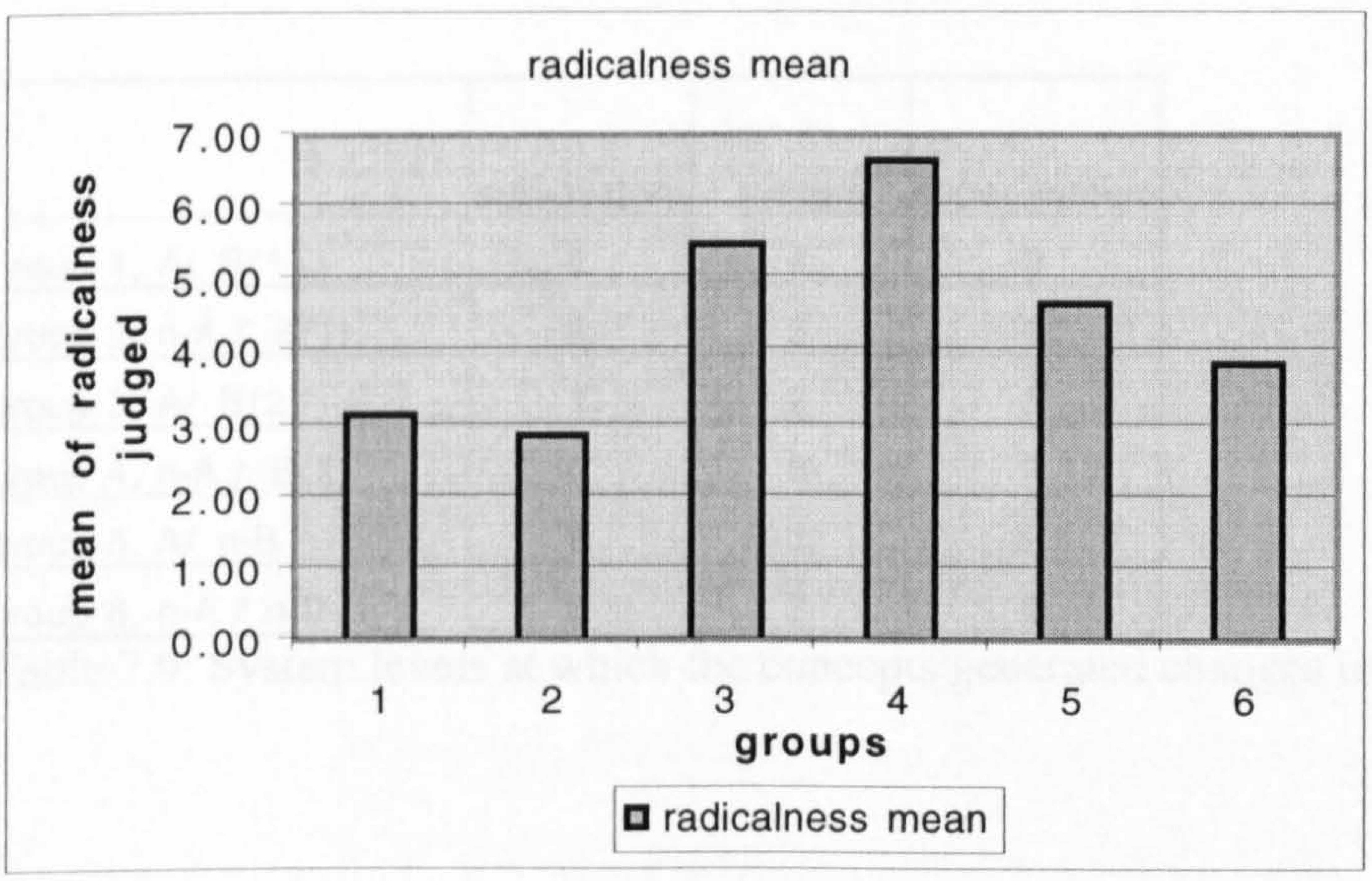


Figure 7.7: Bar chart showing means for radicalness scores

The chart shown in figure 7.7 shows that groups 1, 2 and 6 scored particularly low whilst groups 3 and 4 scored high. The pattern in this data suggests that there may be an inverse link between the radicalness and the appropriateness scores. An additional statistical test was conducted to check this negative correlation. The Spearman correlation coefficient ($r=-0.6955$, $p<0.001$) confirmed the negative relation between the radicalness and appropriateness criteria.

Group 4 had a particularly high radicalness score. Looking at the final concept groups 4 developed shows that they were the only group to propose a new *technology*. All other groups developed a specific *product* concept. The outcome from group 4 is more typical of the type of outcome that might be expected from TRIZ tools. This finding suggests that TRIZ tools could be used to develop radical new technologies but may not be particularly well-suited to design teams generating new product concepts.

The final concept displays evidence of problem solving at higher system levels (H5). This categorical data was too sparsely populated to perform any statistical analysis and is therefore treated descriptively. Table 7.9 shows the number of judges that voted for each of the three categories: sub-system, system or super-system. The table shows that for most concepts (groups 1, 2, 4 and 6) there is reasonable agreement on the level at which the concept generates changes in dishwashing.

	sub-system	system	super-system
group 1, A/ B(1)	2	4	0
group 2, n-A / B(1)	3	3	0
group 3, A/ B(2)	1	2	3
group 4, n-A / B(2)	0	3	3
group 5, A/ n-B	3	1	2
group 6, n-A / n-B	3	3	0

Table 7.9: System levels at which the concepts generated changes in dishwashing

In two cases there was less agreement between the judges (group 3 and 5). Taking a closer look at these groups' final concepts shows that these were the concepts that were most difficult to summarise in two powerpoint slides. These concepts can be interpreted in different ways and perhaps did tackle problems at several different system levels. This system level indicator was not as useful as the other judging criteria used in this experiment.

Use of IFR statements (A)

A two-way Mann-Whitney test was performed to check the statistical significance of the difference between the groups using the tool (A) and those with no method (n-A) and the various judging criteria. The outcomes were: originality (χ^2=-0.85, p=0.3934), appropriateness (χ^2=-1.13, p=0.2577), environmental relevance (χ^2=-2.42, p=0.0154) and radicalness (χ^2=-0.05, p=0.9616). This showed that the use of the IFR statements did significantly affect the judged environmental relevance of their final outcomes.

Subsequently, the frequencies of the four environmental relevance scores were added up for all the groups in each condition (A or n-A), totals are shown in table 7.10 below. The table shows that the groups *not* using the IFR statements tended to end up with a final concept that was scored higher by the expert judges for environmental relevance.

	not env. rel. (1)	(2)	(3)	env. rel. (4)
A, groups 1, 3, 5	6	8	4	0
n-A, groups 2, 4, 6	2	5	10	1

Table 7.10: Totals for environmental relevance scores of groups using IFR statements

Looking at the groups' design interests summarised in table 7.3 shows that, by coincidence, the groups that had the higher environmental relevance score (n-A) were also the teams that had more images of nature and society on their team picture boards. These teams might have been inherently more interested environmental design and may therefore have kept environmental improvements as a higher priority.

Use of contradiction tools (B1 and B2)

Kruskal-Wallis one-way analysis of variance was performed to check the statistical significance of the differences between the three different conditions - groups without tools (n-B), groups using physical contradictions (B1), groups using technical contradictions (B2) - and the judged criteria. The outcomes were: originality (χ^2=2.34, p=0.3108), appropriateness (χ^2=12.86, p=0.0016), environmental relevance (χ^2=3.59, p=0.1662) and radicalness (χ^2=18.44, p=0.0001). This meant that the radicalness and appropriateness were affected by the independent variables. The pair-wise comparisons for radicalness table 7.11 shows that there is a statistically significant difference between all three different conditions, allowing conclusions to be drawn on those variables for the different conditions.

	B1 (physical contr.)	B2 (Technical contr.)	n-B (no tool used)
B1		***	*
B2			**
n-B			

ns = not statistically significant
* = p<0.05 ** = p<0.01 *** = p<0.001

Table 7.11: Mann-Whitney pair-wise comparisons for the statistical significance of radicalness scores between the different contradiction tools used

Looking back at figure 7.7 shows that the technical contradictions contributed to more radical final outcomes, whereas the physical contradiction led to more incremental outcomes. The groups in the control condition produced results in between the other two conditions.

	B1 (physical contr.)	B2 (Technical contr.)	n-B (no tool used)
B1		***	Ns
B2			Ns
n-B			

ns = not statistically significant
* = p<0.05 ** = p<0.01 *** = p<0.001

Table 7.12: Mann-Whitney pair-wise comparisons for statistical significance of appropriateness scores between different contradiction tools used

The pair-wise comparisons for appropriateness table 7.12 show that there is only a statistically significant difference between the groups using the physical contradictions (B1) and the groups using the technical contradictions (B2). Having established a possible inverse relationship between radicalness and appropriateness earlier, it is not surprising that these two criteria come up together as statistically significant. This data check strengthens the inverse relationship suggested between radicalness and appropriateness.

7.3.2 Qualitative Data

Table 7.13 summarises the researcher's observations on the workshop processes based on the complete transcripts.

	group 1.... A/ B(1)	group 2.... n-A/ B(1)	group 3.... A/ B(2)	group 4.... n-A/ B(2)	group 5.... A/n-B	group 6.... n-A/n-B
step 1	briefing stage, no recorded output	briefing stage, no recorded output	briefing stage, no recorded output	briefing stage, no recorded output	briefing stage, clarification of term 'environmental impact' for one member of the team	briefing stage, no recorded output
step 2	they did a very good job at analysing the problems not just from booklet. Probably the best use of the form	lots of ideas but most based on the dishwasher booklet, they attempted to use the form, but it did not create new directions. Some problem pairs not understood.	they spent lots of time doing this, but a lot of it seems to be based on the dishwasher booklet	several interesting points were raised and even translated into 'problems and elements', which were totally lost on the form. (restrictive?) a conventional problem pair was selected	they identified an original (interesting) problem theme, but they did not fill in much in the form. Lots of time spent on the post-it notes and not enough problem pairs	lots of post -it notes were produced but most based on the dishwasher booklet, they did not use the notes parts of the form to spin off new ideas, the instructions could have been clearer
step 3	tool not used in intended way: the ideas in the boxes are not linked (versions of each other). However ideas discussed did feed through to the following stages	there were clear differences between the team members ideas (incremental -radical), the only group to have recycling issues included before the life cycle form.	In use of IFR tool very little emphasis on environmental aspects	they used the groupings 'soft ideas' and 'hard ideas' which recognises the diversity of attitudes (?) in their group	tool not used in intended way: the ideas in the boxes are not linked (versions of each other). One genuinely new idea: 'automated hand washing aid'	generated plenty of ideas around the problems, but one strong env. concept taken through: a system change for anew type of dishwasher
step 4	only groups to honestly acknowledge the potential negative impact of their concept, i.s.o. grafting on good environmental features in the boxes provided on the form	they distilled a lot of their environmental ideas in the form and came up with some new ones. Their form had a lot of content. Evidence of substantial env. des knowledge	the life cycle aspects of the form stimulate thoughts on environmental issues. Evidence of substantial env. des. knowledge	softer issues seem to have got lost, not equal attention to all aspects of the life-cycle, some new ideas did emerge: 'charged by activities around the house'.	one participant developed ideas through sketching, they were the only group to fill in the form at a similar level to the example. Not that much concern about the impact of their concept.	their concept is fundamentally better during the use phase , therefore perhaps relative little time was spend on the life-cycle boxes
step 5	briefing stage, no recorded output	briefing stage, no recorded output	briefing stage, no recorded output	briefing stage, no recorded output	briefing stage, no recorded output	briefing stage, they brainstorm the features of the existing concept that are useful for their competition entry
step 6	i.s.o. looking at their concept, they went back to earlier issues. The separation principles were understood but only matched to the novel ideas that they had had before.	they started off by looking at some bigger issues but then the separation principles were used (and understood) and only matched to the novel ideas that they had had before.	not identified problems but solution directions, however these issues have been translated into contradictions very well and produced detailed env des ideas	went back to their first issues (obvious ones), they got the hang of sequence but got contradictions wrong sometimes. persisted to find a box in matrix with numbers. 'feedback' new issue	nothing new developed: making statements about the potential , env. benefits of their concepts, interesting: flexible load size, long life (integrated), teaching aid for old.	became a bit repetitive, nothing new emerged at this stage
step 7	for their final concept they simply moved towards the existing design, providing a more incremental solution. Only group that didn't use the life cycle boxes to specify env. features	at this stage they went into some more detail on the life-cycle stages and summarised other options for the life-cycle of the same concept but with slightly altered features.	blank: ran out of time or commitment, step six provided them with ideas that could have been included in the sheet	blank: ran out of time or commitment, step six provided them with a couple of ideas that could have been included in the sheet	blank: ran out of time or commitment, more detailed drawing of the final design	blank: ran out of commitment (this groups finished early) , drawing of counter-top detail of the final design.
summary	This group created a concept based on the combination of a number of ideas or features: there was no strong concept selected. They proposed a highly automated cupboard style washer (storage), which included: intelligent loading tray for dirty and delicate area, ultrasonic cleaning	this group's concept revolved around removing back strain and combining a number of environmental features. There is now clear direction in which the design evolved between step 4 and 7.	they came up with a dishwasher and storage unit situated in the dining table that makes serious changes to the user interface and ease of use, but no evidence of environment in their thoughts.. after filling in the life cycle part of step 4 (step 5 instructions?) when using the tool in step 6 they did address more environmental issues	they developed a new dishwasher technology and special plates, based on 2 of their original ideas: 'post-it note plates' and 'sand blasting'	The washer is a continual input, output machine where the output is a 'surprise' game. Its has a very big LCD screen interface for the 'game element'. they developed a washer that addresses mainly social (family) issues, unclear whether it addresses drying issues for energy reasons or just activity.	the washer takes a basket of washing through the countertop, and soaks the dishes for a while in the base of the machine. The subsequent cycle is short and the dishes are returned to the counter to dry at room temp. they produced an valid concept for a more environmentally friendly dishwasher in a very short time.

Table 7.13: The observations on the process from the transcriptions

Several teams had problems using the tools correctly or gaining any new ideas or insights from the use of the tools. The IFR statements (A) were not used in the intended way by two of the three teams (groups 1 and 5) and the team that did use the tool correctly did not use it to explore environmental aspects (group 3). The two teams (groups 1 and 2) using the separation principles to solve physical contradictions (B1, step 6) each matched the separation principles to ideas they had before, instead of using the tool to generate new ideas or insights.

This incorrect use of the tools might explain the results from the data regarding the use of the contradiction tools which showed that the technical contradictions contributed to more radical but less appropriate final outcomes, whereas the physical contradiction led to more incremental and appropriate outcomes. The groups in the control condition produced average results. This would indicate that if the tools are used incorrectly the effect may be more incremental final outcomes and perhaps no tool is better than tools used incorrectly.

The technical contradictions were used more successfully; both groups 3 and 4 addressed environmental issues when they used the technical contradictions (B2, step 6). These teams did gain some new ideas or insights for their project; however, these were not recorded as part of the final concept in step 7. The positive outcomes from the use of the technical contradictions were mainly recorded in the forms and notes from step 6.

The quantitative data suggests that using *some* tools in design teams is beneficial when step-change results are sought. The qualitative transcript data shows that early in the problem identification stage some of the teams members were working on much more radical concepts than others. When they got their ideas together, they seemed to revert to more incremental ideas. This experiment suggests that multi-disciplinary teams will tend towards less radical ideas as reaching consensus is often problematic. This data strengthens the case for providing some tool or method to make sessions more constructive (chapter 4).

The second part of the qualitative data was from the general comments made by the judges on the strengths and weaknesses of the concepts. From these comments it is possible to say that these experts were positive about concepts including social and ethical issues alongside environmental ones. Most of the judges' concerns about the appropriateness of the concepts were specifically about the marketability of them. The judges also made several comments on the changes in consumer behaviour that would be required as a consequence of the concepts.

7.4 Discussion

It was hypothesized that the use of the TRIZ tools would improve the outcomes from eco-innovation workshops. The use of the TRIZ tools would improve the outcomes in terms of originality (H1), appropriateness (H2), environmental relevance (H3) and radicalness (H4). The outcome from the workshop would also display evidence of problem solving at higher system levels (H5). These criteria have been investigated in turn, and links between them are discussed below. Furthermore, the data has been checked for the specific effects of the IFR statements (A) and contradiction tools (B1 and B2) on the outcomes from the workshops and results are discussed in section 7.4.1.

System level, originality and radicalness

From the quantitative data some links have been shown between these three criteria. Some link is suggested between the system level and radicalness criteria. This is not too surprising as the definitions of these criteria were quite similar on the questionnaire. Solutions at the higher system level are easily marked as more radical. Solutions at the lower system levels may be radical in themselves and support step-change design, but it is difficult to judge the overall extent to which they will improve the way the function is fulfilled.

The originality measure revealed relatively small differences between groups. The system level measure was statistically not as robust as the other judging criteria used in this experiment. The radicalness measure was the most useful of these three indicators

Radicalness and appropriateness

The quantitative data has suggested that there may be a negative correlation between these criteria. An additional statistical test confirmed the negative relation between the radicalness and appropriateness criteria. This result throws light on the main problem with eco-innovation: step-change radical ideas are desired but rarely recognised as suitable ideas to be implemented. The fact that many of the step-change ideas are discarded as 'inappropriate' following workshops may explain why there are so few real examples of successful eco-innovation.

Previous authors have identified a similar dilemma. Snoek, Christiaans and Hekkert (1999) for example, found that there were discrepancies between their originality and appropriateness scores, and concluded that their participants found it difficult to translate original ideas into appropriate solutions. They recommended training or tools to translate original elements from a solution space into appropriate design solutions. The data reported in this chapter, confirms that creating step-change (radical) innovative (original and appropriate) concepts is inherently difficult and may be the main barrier to eco-innovation. Eco-innovation requires the balancing of opposing criteria: radical vs. appropriate, original vs. appropriate. Eliminating contradictions is an important premise of TRIZ. This conclusion indicates that TRIZ does have something to offer eco-innovation if it is able to help eliminate such contradictions.

Appropriateness and environmental relevance

The patterns in the data for appropriateness and environmental relevance indicated that these criteria might be linked; perhaps concepts which can be imagined implemented are more likely to be scored as environmentally relevant. From the judges' comments on strengths and weaknesses (discussed in section 7.3.2) some new ideas emerge to improve the environmental relevance criteria with which to judge early stage concepts (summarised in conclusions). Developing these judging or selection criteria could play a significant role in ensuring both that more concepts get developed further and that the likelihood that they may be taken up in industry is increased. Developing such criteria was not defined as a focus for this thesis, but should be included in further research for eco-innovation.

7.4.1 Benefits of the simplified TRIZ tools

IFR statements

In chapter 6 the IFR statements were selected as a promising tool for eco-innovation because they are based on the concept of ideality, which shows a good fit with the aims of eco-innovation. Furthermore, the worked examples in chapter 6 had shown that IFR statements could be applied at different system levels. IFR statements are also part of the creaTRIZ software (Creax, 2001) where they are used for problem exploration and to generate radical new solution directions.

The quantitative data from this experiment, however, has shown that the IFR statements did not affect most of the criteria judged. The environmental relevance was affected but the concepts created by groups using the IFR statements had low environmental relevance scores. By coincidence, the groups' design interests may have confounded this part of the experiment. The groups that had higher environmental relevance scores – those not using the IFR statements - did have more evidence of design interests in nature and society on their picture boards (see table 7.3). Those groups may therefore have kept environmental improvements as a higher priority.

The IFR statement tool (A) was used early in the process for problem exploration and should have benefited from the participants 'fresh' state, however, the qualitative data showed that this tool was not used correctly by most groups and instructions for its use were probably not adequate.

Physical contradictions

The physical contradictions were included in this experiment in order to compare this simpler version of contradiction-elimination against the more-used technical contradictions. The physical contradiction tool had not been tried out in the worked examples in chapter 6 and is not one of the most-used TRIZ tools in industry. The tool does however provide a simple way to change design-by-compromise practice: one of the fundamental TRIZ discoveries identified in chapter 6 as particularly relevant to eco-innovation.

The qualitative data from this experiment, however, has shown that the physical contradictions were not used in the intended way. The theory seemed to have been understood but the groups matched the separation principles to their ideas and concepts from earlier stages. This indicates that this method was perhaps employed too late in the experiment. In the experiment design the physical and technical contradiction tools were thought suitable for a similar stage in the process. The results showed that the physical contradictions might be more useful for exploring the problem space at earlier stages.

Technical contradictions

In chapter 6 the contradiction matrix and inventive principles were identified as popular TRIZ tools. The successful use of the inventive principles was demonstrated in the worked examples in chapter 6; however, there were no examples of their use together with the contradiction matrix. This experiment set out to test the conventional use of the technical contradiction tool - inventive principles with contradiction matrix – to solve specific problems in fairly well defined concepts.

The quantitative data from this experiment showed that the technical contradiction tool affected the radicalness and appropriateness of the concepts generated. The groups using the tool scored high on radicalness and low on appropriateness for their final concepts. These were unexpected results, as this tool was intended to solve specific problems in defined concepts, in order to translate them into more appropriate solutions. The qualitative data, however, did show that the technical contradiction tool encouraged the teams to work on more of their concept's details. From that point of view it was the most positive tool included in this experiment. The technical contradictions did raise some new and relevant ideas at a fairly late stage in the workshop.

The number of tools tested in this experiment had to be limited. In the worked examples in chapter 6 the trends of evolution were all applied at the lower system level. This was the main reason why the trends of evolution tool was not selected as an independent variable. However, recently TRIZ practitioners have begun to advocate more conceptual uses of the trends of evolution tool. Mann (2000a) for example suggests that the trends can be used to identify new product, process or service opportunities or even to identify new business evolution paths. More recently, Mann and Dewulf (2002) developed the use of the trends further to provide designers with a new tool to identify project aspects with maximum potential for value creation or innovation. With hindsight, perhaps the most conceptual tools – instead of the most popular tools - from TRIZ should have been sought.

7.4.2 About testing these tools

On the task set

There were several instances where the TRIZ tools were not used correctly and the teams did not gain any new ideas or insights from the use of the tools. The task set (to explore domestic dishwashing and generate solution concepts for environmental impact reduction) may have been too vague for these specific problem solving tools or perhaps the TRIZ tools tested are intrinsically more useful when the project is beyond the concept design stage.

There was only one team (group 3) that managed to balance originality, appropriateness and environmental relevance. Their scores across these three criteria were average. This team tried out two TRIZ tools in their session, IFR statements (A) and technical contradictions (B2). Their reasonable scores indicate that this team was comfortable integrating these rather complex tools in their practice. This implies that the number of tools tried out and the complexity of the tools did not make the task impossible.

To test the problem-solving tools perhaps a different type of task should have been set; pre-prepared radical concepts could have formed the starting point. Such an experiment might provide insights into the extent to which the TRIZ tools can help to translate ideas into more appropriate solutions. The dishwashing booklet did enlarge the problem/solution space to some extent but was not included as an independent variable.

The dishwashing booklet

Most of the groups' concepts were developed based on an interesting social or user interface issue. Most of the issues tackled were included in the dishwashing booklet provided. This means that the themes in the dishwashing booklet probably played a significant role in steering the workshop. Other authors have been investigating the role that the information provided plays in workshops (Snoek, Christiaans & Hekkert, 1999;

Pasman, 2002). Their research shows that the information provided does 'direct' designers. This experiment has highlighted the effect of the thematic information provided in the workshops. Developing the information provided in workshops was not a focus for this thesis but the finding suggests that this aspect should be considered in further research.

The PIG

The Problem Identification Game (PIG) was intended to provide a problem-solving focus for the workshop. The qualitative data showed that the use of the problem pairs to explore the problem space was not so successful. It did not help them to diverge and expand the problem space. The form may have been too rigid. However, identifying a single problem pair did strengthen the teams' issue focus; each team did manage to define a single strong concept in their workshop.

Data collection

Using the written output from this experiment provided an efficient way to obtain rich data from this experiment. The concept description forms at step 7 and step 4 included specific boxes to describe the features of the product at different life-cycle stages of the product. These boxes were intended to encourage the teams to highlight the environmental features and issues they had addressed. However, most teams used these boxes as a *stimulus* for new life cycle ideas; environmental issues were tagged onto their concepts by placing statements in the boxes such as: 'it will be designed for recycling' or 'it will be modular'. Only one team (group 1) used the boxes in the intended way.

On the task booklet

Similar to the suggestions made in chapter 4, this experiment indicated that several of the tools would need more than the written instructions provided to be successfully employed. In an industrial environment these tools would be introduced in a training session with worked examples and exercises to improve understanding and adoption. Providing the participants with an opportunity to ask questions is likely to ensure: the correct use of the tools; long term adoption of the tools; and improve the quality of the outcomes from the tools.

7.5 Conclusions

Table 5.3 in chapter 5 identified TRIZ as covering most activities in the design process. Both this study and chapter 6 have now shown that the TRIZ tools tried (popular ones) are not particularly useful in early stage workshops. Most of the TRIZ tools are designed for problem solving at the detail stage, and are best integrated in an ongoing process and may not be particularly suitable for early stage workshops or team design practice. This experiment did show that the more radical ideas likely to emerge from the use of the TRIZ tools are new technology developments rather than new products.

In chapter 5 it was suggested that TRIZ tools might be complimentary to the PIT diagram by helping to translate ideas from the enlarged solution space into more appropriate solutions that have the potential to be implemented. The TRIZ tools tried out have not shown particular potential to translate ideas into more appropriate solutions. The idea that TRIZ tools could be used in a second workshop session to translate ideas from a workshop session using the PIT diagram has therefore been dismissed.

This chapter has highlighted the inherent contradiction in eco-innovation: the objective to create solutions which are both radical *and* appropriate. Eco-innovation might benefit from the development of new selection criteria which would *not* filter out all ideas - from the enlarged solution space - that cannot immediately be adopted in industry. These new criteria for environmental relevance could be developed to include: marketability of new concepts - a different measure of appropriateness - and potential positive changes in consumer behaviour - a different measure for environmental relevance.

The TRIZ tools did support design at different system levels, although that criterion was not as robust as the other judged criteria. This study showed that if problems are to be tackled at the higher levels of the system hierarchy something more explicit needs to be done to introduce the system hierarchy. In future eco-innovation workshops it might be beneficial to investigate system level idea-generation. The workshop could start with a breakdown of the system hierarchy and a task that requires the participants to apply themselves to the higher levels of such a system diagram. Environmental aspects would need to be included in that system hierarchy. The information provided to designers in workshops plays a bigger role than expected. One new idea for including environmental aspects would be to manipulate the information provided and include more specifically environmental themes.

Some of the fundamental TRIZ discoveries are upheld as relevant to eco-innovation. The underlying theory of solving contradictions rather than a design-by-compromise approach is potentially valuable for eco-innovation. The contradiction inherent in attempting to create radical *and* appropriate solutions is yet to be tackled. Practical aspects of applying TRIZ at early stages are equally unresolved. Perhaps the more conceptual tools - trends of evolution or multi-screen thinking - could be used for concept exploration if introduced in the right way. These tools warrant closer investigation and training sessions may provide the key to better use in workshops.

Having established that the TRIZ tools selected were not particularly suitable for early stage workshops, the work done on the simplification of these tools is not dismissed. This experiment was ambitious. The participants were introduced to the simplified versions of the TRIZ tools without guidance or prior training. In workshops that only lasted 2 hours, participants were asked to try two TRIZ tools. They did mostly manage to grasp the essence of the tools and apply them to their own concepts. In conventional TRIZ training, participants are typically briefed on the theory, given instructions and examples of each TRIZ tool for about an hour. They are the typically given 20-30 minutes to practise the use of the tool on a prepared problem. The simplified versions of the TRIZ tools and the accompanying forms tested in this chapter were presented to the TRIZ research community (Jones, Harrison and Stanton, 2001) where interest was shown for their use in training sessions.

Chapter 8 Discussion and Conclusions

This research has made a significant contribution to eco-innovation by proposing and testing tools to facilitate early-stage workshops. Important aspects of the thesis are the experiments that were carried out to test the tools proposed.

This chapter relates the main findings to the model for eco-innovation from chapter 1. Several important findings on the use of tools and methods to facilitate the early stages of eco-innovation are summarised. The research has also helped define attributes of successful outcomes from eco-innovation and provided insights into design research for early-stage workshops. This chapter concludes with a recommended process for eco-innovation.

8.1 How the studies conducted relate to the eco-innovation model

This section summarises the studies conducted in the order in which they are reported in the thesis. Figure 8.1 shows the original model for eco-innovation drawn up which provides the framework for the research contributions. This section explains how the variables were explored, manipulated or controlled in the studies and the model is used to relate the studies to the framework. This same model is extended in section 8.4 to summarise the most important findings from the studies.

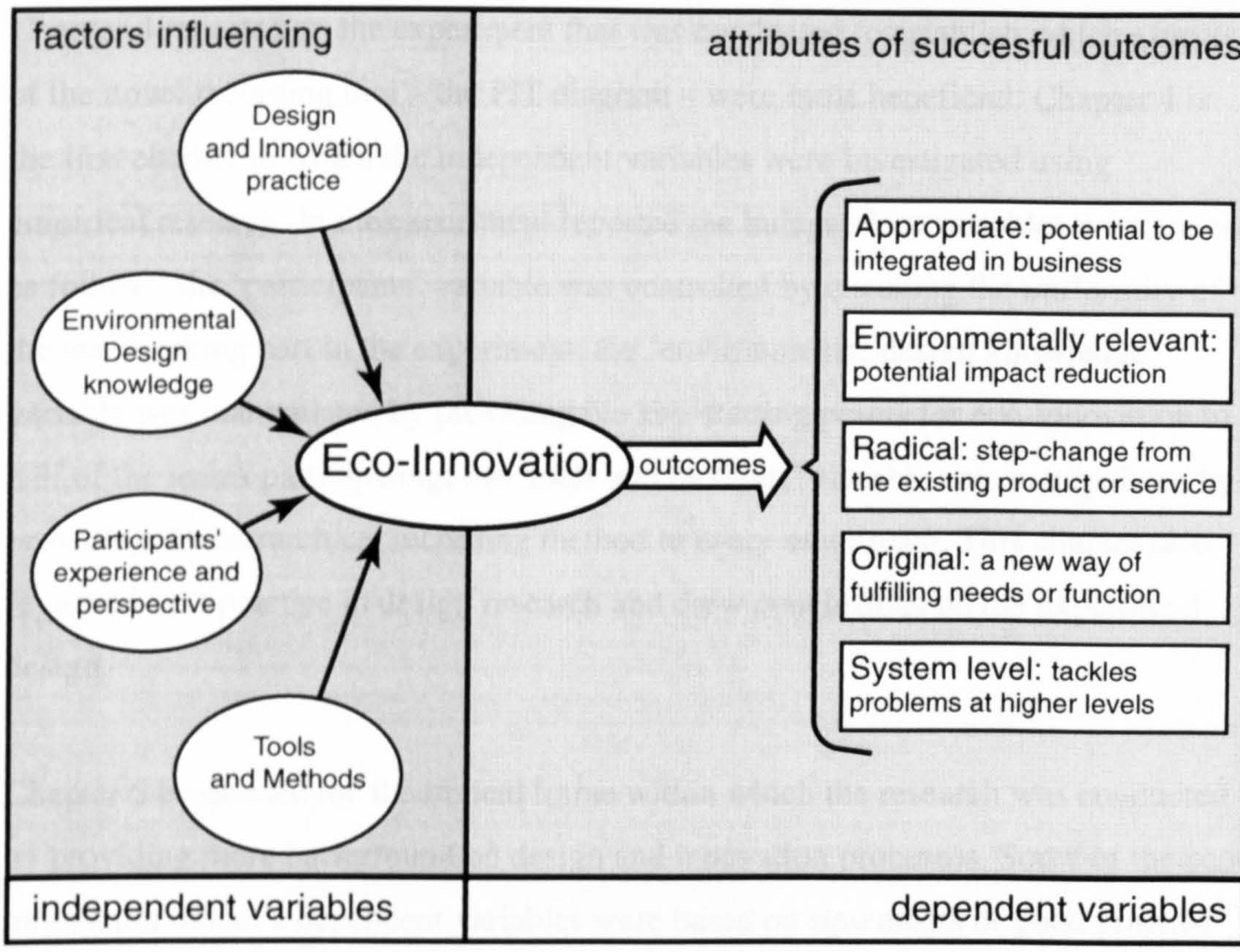


Figure 8.1: Model for eco-innovation

Chapter 1 defined eco-innovation and explained the focus and boundaries of the research. The model of eco-innovation was drawn up as a framework for this thesis. Chapter 2 contains the main literature review, it provided a brief review of: the terminology, drivers and obstacles of environmental design; tools for environmental design; and case studies that include early-stage workshops. Chapter 3 took a closer look at one early-stage method and the output from one environmental design workshop in relation to the design process. Two tools were developed to assist the evaluation; one of them – the Product Ideas Tree (PIT) diagram – was developed further as a recording tool for use in eco-innovation workshops. In chapters 1, 2 and 3 the eco-innovation model's independent variables were not manipulated or controlled. These chapters developed some of the definitions of the 'factors influencing' eco-innovation and highlighted particular points of interest for this thesis. Chapter 3 began to focus on the 'tools and methods' variable to improve eco-innovation.

Chapter 4 reported on the experiment that was conducted to establish which aspects of the novel recording tool – the PIT diagram – were most beneficial. Chapter 4 is the first chapter in which the independent variables were investigated using empirical research. In the experiment reported the independent variables were treated as follows: the 'participants' variable was controlled by checking the uniformity of the teams taking part in the experiment; the 'environmental design knowledge' variable was manipulated by providing the key-starting points for eco-innovation to half of the teams participating; the 'tools and methods' variable was manipulated by providing the hierarchical recording method to every other team. This chapter also reviewed best practice in design research and drew conclusions on the experiment design.

Chapter 5 broadened the theoretical frame within which the research was conducted by providing more background on design and innovation processes. Some of the eco-innovation model's dependent variables were based on statements of good practice which were distilled from a review of innovation theory. The 'system level' and 'radical' variables were included in the model as attributes of successful outcomes. A review of mainstream tools to structure innovation identified one method as a particularly promising approach for eco-innovation: the Theory of Inventive problem Solving (TRIZ).

Chapter 6 presented theoretical and practical studies to assess TRIZ's potential to improve eco-innovation. The diversity of TRIZ was explored and aspects that inherently support eco-innovation were highlighted. TRIZ practitioners were interviewed and three worked examples were presented in which TRIZ tools were used for environmental improvement. The independent variables were not manipulated or controlled but findings from the studies and interviews informed several of the 'factors influencing' eco-innovation further. The eco-innovation model's dependent variables were established and used to assess the outcomes from the three worked examples. Finally, TRIZ tools were selected for testing in an eco-innovation workshop.

Chapter 7 reported on the experiment conducted to test simplified versions of the selected TRIZ tools in workshops. In the experiment the independent variables were treated as follows: the 'participants' and 'environmental design knowledge' variables were controlled by checking participants profiles and putting together uniform teams; the 'tools and methods' variable was manipulated by providing each team with a different combination of tools to try out in their workshop. The process and idea capture was controlled by providing task booklet and feedback forms. Conclusions were drawn on the use of the tools for eco-innovation workshops and on the criteria used to judge good eco-innovation practice.

8.2 Validity, reliability and generalisability of research contributions

By drawing the model for eco-innovation based on theories and studies, and using it as a framework for the new tools proposed, it is argued that the proposed tools have good construct validity. This research has not investigated whether the tools proposed would consistently produce the same types of outcomes with different participants in subsequent workshops. The tools proposed have not been tested for their predictive validity or the reliability of the results. Testing the predictive validity or the reliability of the results is not common in design research, but is an important goal for future research. Working in this relatively young research field, design researchers are keen to inform and improve design practice by proposing new tools and methods. Both new and existing tools and methods are continually developed using an iterative process in which empirical research suggests improvements.

This research set out to make a contribution to step-change environmental impact reduction. The research contributed two novel tools to facilitate the practice of eco-innovation. Both these tools and several of the findings from the experiments conducted are valid for other innovation processes where step-change is sought. The recommended process for eco-innovation described in section 8.7 is equally valid for any innovation process. All the findings on tools and methods, the role of early-stage workshops and the experiment design are applicable - with some adaptation - to early stages of other innovation processes. From the findings on attributes of successful outcomes, it is important to note that creating radical *and* appropriate concepts is inherently difficult in any innovative project. If the innovation process *is* to result in environmental impact reduction the thematic information provided and the selection of ideas and concepts needs to be adapted to promote environmentally relevant ideas and concepts and the system hierarchies drawn up must include environmental aspects.

8.3 Contributions made to the model for eco-innovation

All research contributions can be framed in relation to the model for eco-innovation, the most important contributions made, however, have emerged through proposing and testing the PIT diagram and the simplified TRIZ tools.

A novel idea-recording tool – the Product Ideas Tree (PIT) diagram – evolved from some of the early exploratory research. The PIT diagram helps structure the process and the outcomes from workshops in eco-innovation by improving the capture of ideas. The PIT diagram uses environmental starting points to generate ideas that radiate across the surface of a diagram to provide a greater span of environmentally relevant ideas. The PIT diagram presents each workshop participant's contributions in relation to the 'bigger picture' in order to facilitate communication within the teams.

The Theory of Inventive problem Solving (TRIZ) was identified as an approach which can support radical innovation and design at different system levels and was therefore selected for further investigation. One of the reasons TRIZ showed great potential was that it contains numerous specific tools and several fundamental principles regarding innovation. It was suggested that TRIZ tools could be complimentary to the PIT diagram and the research could be of interest to both the environmental design and TRIZ communities. The selection of TRIZ tools for use in eco-innovation was based on interviews and worked examples. Subsequently, those popular TRIZ tools were simplified for use in early-stage workshops.

The workshop experiments conducted on the PIT diagram and the TRIZ tools provided several important findings on the use of tools to facilitate early-stage workshops for eco-innovation. The main findings are summarised below in section 8.4.

8.4 Tools and methods for early stages of eco-innovation

The main findings on the use of tools to facilitate early-stage workshops for eco-innovation were as follows:

- When selecting tools their intent, complexity and instructions need to be carefully considered.
- The take up of new tools is mainly determined by their ability to integrate into existing processes.
- The discoveries of contradiction elimination and ideal systems from TRIZ could strengthen the foundation of tools and methods.
- System-level idea generation or problem solving requires the drawing up of a system hierarchy.
- Providing prompts or thematic information can be used to affect the outcomes from workshops.

Each finding is discussed below with the aid of the expanded version of the original model for eco-innovation shown in figure 8.2. Figure 8.2 shows all the different topics explored, manipulated or controlled in each chapter. The small numbers indicate in which chapter contributions were made to those topics. The colour-coded circles have been used to link each finding on the use of tools - described in more detail below - to the topics in expanded model. This figure also provides a reference for section 8.5 which summarises the conclusions on the attributes of outcomes from eco-innovation.

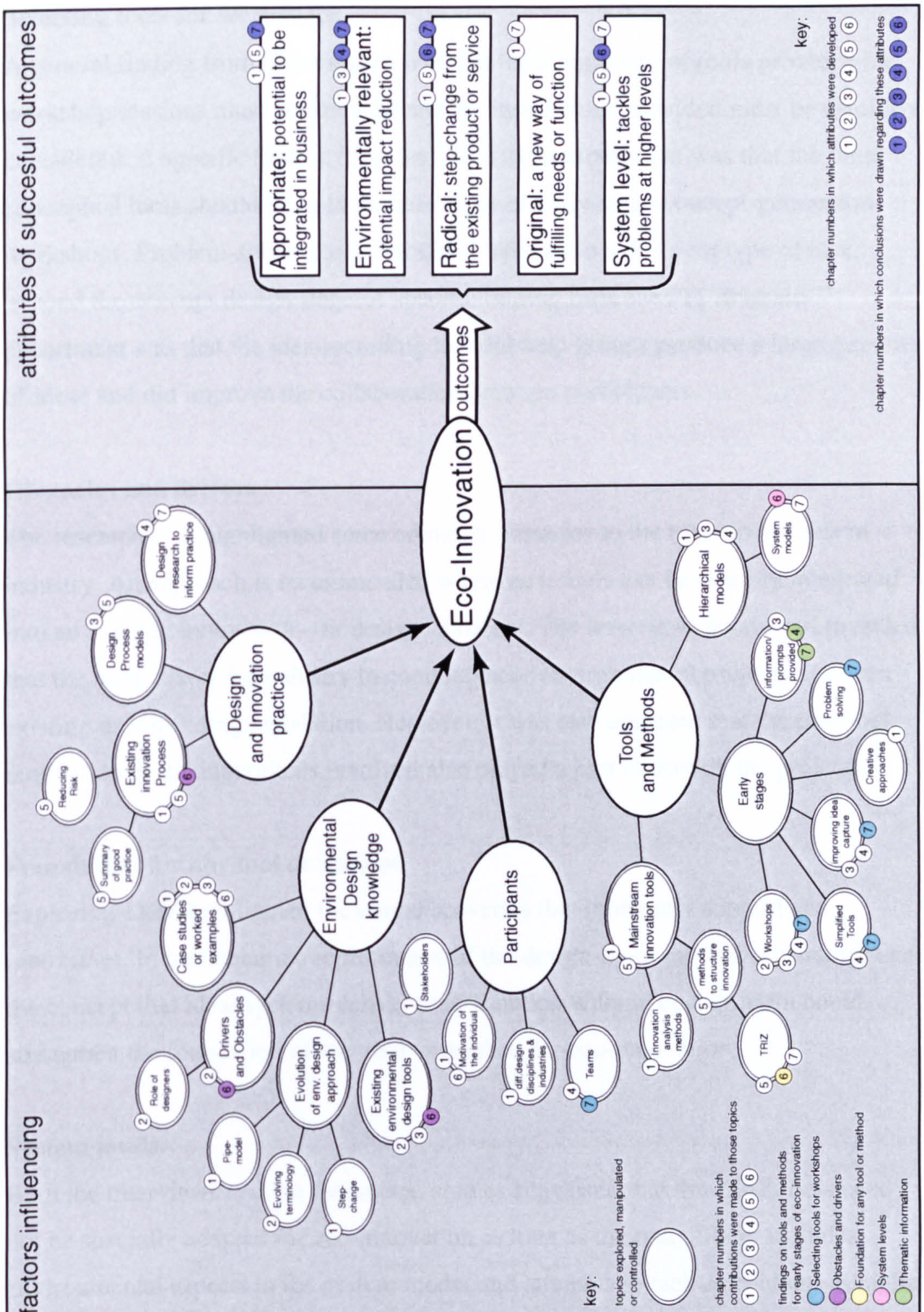


Figure 8.2: Summary of contributions made to the model for eco-innovation in each chapter

Selecting tools for workshops

A general finding from this research was that the complexity of tools provided for workshop sessions must be balanced and the instructions provided must be carefully considered. A specific finding from the TRIZ tools experiment was that the more conceptual tools should be used in these types of early-stage concept-generation workshops. Problem-solving tools should be applied to a different type of task, beyond the concept design stage. A specific finding from the PIT diagram experiment was that the idea-recording tool did help groups produce a large quantity of ideas and did improve the collaboration between participants.

Obstacles and drivers

The research also highlighted some common obstacles to the take-up of tools in industry. An approach is recommended where new tools can be flexibly integrated into an existing innovation – or design - process. The interviews conducted revealed that the main driver for industry to conduct these environmental projects has been existing or impending legislation. However, it was also apparent that the personal motivation of the individuals involved also played a part in driving the projects.

Foundation for any tool or method

Exploring TRIZ highlighted the core discoveries that inherently support eco-innovation. In particular the replacement of the design-by-compromise paradigm and the concept that ideal systems deliver their function without cost or harm could strengthen the foundation of any tool or method for eco-innovation.

System levels

Both the interviews and the theoretical studies suggested that the TRIZ tools need not be specially adapted for eco-innovation as long as the practitioner includes environmental aspects in the system model and attempts to tackle problems at higher levels of that system. Creating the worked examples of TRIZ for eco-innovation suggested that some TRIZ tools could be more easily applied at different levels in the system model. The workshop experiment however, did not provide many insights into the activities at these different system levels. If eco-innovation is to solve problems at higher levels of the system hierarchy then the drawing up of system models must be specified at some stage of the process. Specific approaches to system level problem solving or system level idea generation are yet to be explored.

Thematic information

The PIT diagram experiment provided insights into the role of the key-starting points for eco-innovation in the workshop session. The use of these prompts showed that information provided in workshops will only affect the outcomes if they are new to the participants. The experiment conducted on the TRIZ tools revealed that the thematic information provided in workshops steers the participants and affects the outcomes from workshops. Developing specific thematic information to steer workshops could be beneficial of early-stages of eco-innovation.

8.5 Attributes of successful outcomes from eco-innovation

The numbered circles on the right of figure 8.2 show the chapters in which the attributes of successful outcomes from eco-innovation were developed and the chapters in which the main conclusions were drawn. The conclusions on the attributes of successful outcomes from eco-innovation are summarised in this section.

In the PIT diagram experiment – reported in chapter 4 - the only attributes of the workshop outcomes investigated were the quantity of ideas and the environmental relevance of those ideas. That experiment showed that the criteria for judging successful outcomes and the judging process itself could be made more informative.

The attributes were subsequently developed further from theories of good innovation practice. The first use of all five attributes as judging criteria was in the worked examples of TRIZ for eco-innovation – in chapter 6. The assessment of the outcomes from the worked examples using those criteria indicated that solutions at the higher system level are easily marked as more radical; implying an intrinsic link between the system level and radicalness criteria.

In the TRIZ tools experiment - in chapter 7 - radicalness, appropriateness and environmental relevance were found to be the most useful of the attributes used as criteria to judge the outcomes from workshops. Developing judging or selection criteria for eco-innovation further would be one way of ensuring that the more appropriate and environmentally beneficial concepts from workshops get developed further. However, creating innovative - radical *and* appropriate - concepts is inherently difficult. Step-change – radical - ideas are desired but are rarely recognised as suitable – appropriate - to be implemented. The research suggests that eco-innovation requires the contradiction between radicalness and appropriateness to be resolved.

The findings regarding the attributes of successful eco-innovation can be summarised as follows:

- Radicalness, appropriateness and environmental relevance are useful criteria to judge the outcomes from workshops.
- Developing the judging criteria could promote further development of ideas and concepts in an eco-innovation process.
- Eco-innovation requires the contradiction between radicalness and appropriateness to be resolved.

8.6 Design research for early-stage workshops

The review of previously conducted environmental design case-studies in section 2.4.1 revealed that workshops have been successfully used, however, when tools or methods have been introduced their effectiveness has not been investigated. In this research tools have been developed *and* tested, therefore several findings relate to the role of early-stage workshops and the experiment design. The conclusions regarding workshops and experiment design can be summarised as follows:

- Linear models of the design process should not be used to structure early-stage workshops.
- Tools training, facilitation and alternative recordings are recommended as ways to improve the outcomes from workshops *and* the quality of the experimental data.

- The stage at which different tools are introduced in the workshop affects the usefulness of the ideas and concepts.

The PIT diagram used as an evaluation tool in chapter 3 highlighted that the outcomes from early-stage workshops can be different types of ideas suitable for different stages of the design process. A linear model of the design process is therefore not particularly beneficial in early-stage workshops.

The findings from the PIT diagram experiment in chapter 4 were that briefing for new tools, getting consistent recordings of outcomes and general discipline in the sessions can all be problematic in controlled workshop experiments. Tools training, facilitation and alternative recordings could improve the quality of the experiment design and the outcomes from those workshops.

The findings that emerged from the TRIZ tools experiment in chapter 7 were that the self-briefing procedure was useful to control the experiment but again providing training with new tools is likely to improve the quality of the outcomes. Also, the *stage* at which different tools are introduced in the workshop plays a role in the adoption and success of the outcomes from the eco-innovation workshop.

8.7 A recommended process for eco-innovation

An important aim of this research was to facilitate the generation of radical environmental ideas and help develop them into appropriate solutions that have the potential to be taken up in industry. Concepts need to be developed to a stage whereby the product's business case becomes evident and its chance of being taken through to implementation can increase. To ensure that the most appropriate and environmentally beneficial concepts get taken further a process is needed that will transform radical ideas into appropriate and operational solutions. A recommended model for such a process is described in this section.

The sequential model presented in figure 8.3 brings together some of the recommendations from this research. The process consists of five steps to move radical environmental ideas towards marketable products. The research that would be required to develop and integrate the elements of this recommended process into practice are summarised as recommendations for future research at the end of this section.

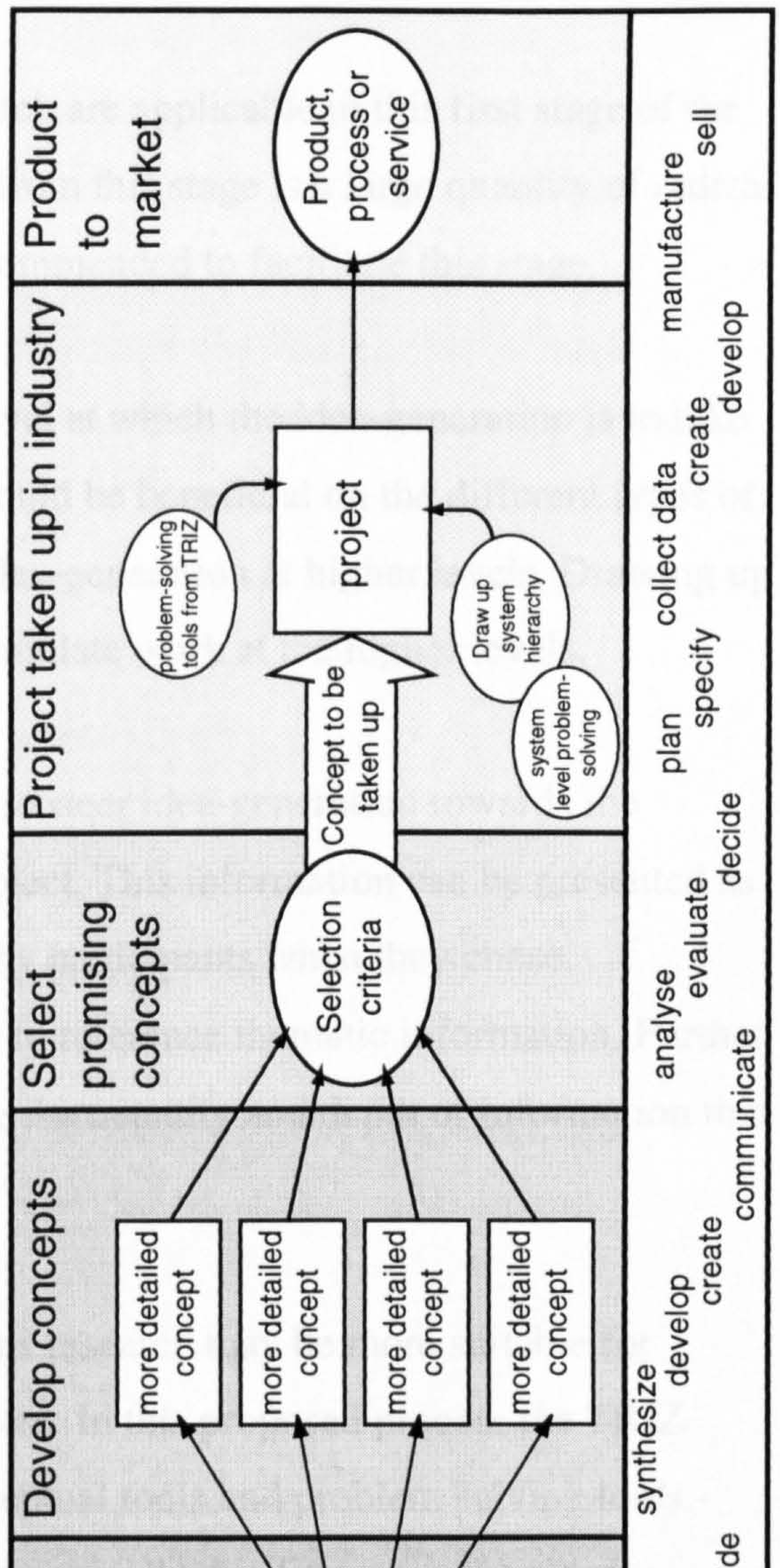


Figure 8.3: Recommended process for eco-innovation

1. Conduct early-stage workshops

The main contributions made in this research are applicable to this first stage of the proposed process. The outcome expected from this stage is a large quantity of radical ideas. Four different types of tools are recommended to facilitate this stage.

A system hierarchy is drawn up and the level at which the idea-generation is to take place is made explicit. Further research would be beneficial on the different types of system models and on the facilitation of idea-generation at higher levels. Drawing up the system hierarchy may be enough to stimulate work at the higher levels.

Specific thematic information is prepared to steer idea-generation towards the important environmental issues for the project. This information can be presented as 'snippets' of information to be picked up by participants when they chose. Information booklets provide an easy way to reference thematic information. Further research would be beneficial to investigate the quantity and depth of information that should be provided.

Some of the popular TRIZ tools tried in this research may be more suitable for problem solving at later stages of the process. In this proposed process the TRIZ tools have been split into two types - conceptual tools and problem solving tools - each to be used at a different stage in the process. At this first stage the more conceptual tools are introduced. Further research could investigate different ways of employing the separation principles, the trends of evolution and the 9-screen diagram. If new tools are developed they should be based around the concept of ideality and contradiction elimination.

Throughout early-stage workshops the PIT diagram is used as the tool to capture all the outcomes. One recorder or facilitator is trained in the method prior to the workshop. Further research on the PIT diagram should look at its role in later stages of the process and whether a computer-aided version could be developed for continual updating and referencing throughout the process.

2. Select promising ideas..... 3. Develop business concepts..... 4. Select promising concepts

This research has highlighted the inherent difficulty in producing radical and appropriate concepts. In the proposed process this difficulty was overcome by acknowledging the gap that exists between the large quantity of radical ideas generated in the early-stage workshops and the eventual selection of a suitable concept to be taken up as a project in industry. Three stages are suggested to fill the identified gap: selecting promising ideas from the radical ideas generated; developing the ideas into more detailed concepts; and selecting the concepts most promising for business and environmental benefit.

Having comprehensively captured the output from the early-stage workshop the PIT diagram facilitates the selection of promising ideas. Suggestions for new selection criteria from this research were 'marketability of the concept' and 'the concept's potential to change user behaviour'. The judging criteria for successful eco-innovation could be developed further by interviewing environmental design experts to collect more suggestions. The usefulness of any new set of selection criteria needs to be tested in case studies.

The 'develop concepts' stage is where the ideas selected are developed into more substantial business concepts. This is a phase of detailing the concept to a level where a business case can be made. This stage involves synthesizing and developing promising *ideas* into promising *concepts*. These are conventional design activities and the mainstream design discipline provides approaches and examples. The main concern for the eco-innovation process is to ensure that the environmental aspects of the ideas generated in the workshop do not get lost at this stage.

To select the most promising direction the business concepts need to be assessed with techniques which look at this 'conceptual' output but still provide some evidence of the business concept's potential environmental impact reduction. The best tools available to compare the environmental relevance of concepts are the LiDS-Wheel and the Eco-compass. The best tools to compare the business potential of concepts developed are the mainstream analytical methods that help reduce risk in innovation processes. Both types of tools need to be tested in case studies.

5. Project taken up in industry..... 6. Product to market

At this stage a concept has been taken up in industry and is being developed as a marketable product, process or service. This final stage follows a typical new product development process. This research has suggested that problem-solving tools are likely to be more useful at this stage than in early-stage design workshops. To ensure that the problem-solving efforts are focussed at the higher system levels, a system hierarchy must be drawn up. To learn more about these final stages of getting a product to market whilst ensuring the best possible environmental impact reduction, existing implemented eco-innovations should be studied.

8.7.1 Recommendations for future research

This section summarises the recommendations for future research. Future studies should be conducted to gain insights into:

- Which system models are easy to adopt;
- Which system models can stimulate work at the higher levels;
- Ways that idea-generation at higher levels of the system hierarchy can be stimulated;
- How much and what kind of thematic information provides the most environmentally relevant results from workshops;
- Which of the other TRIZ tools could be beneficial in workshops;
- How the PIT diagram could be made more useful throughout the process;
- Further development of the selection criteria to improve the eco-innovation process;
- Predictive validity and reliability of any of the tools and methods in the proposed process.

The recommendations made above are suitable for further research within the academic context. However, valuable contributions to eco-innovation would also be gained from more industrial case studies. These case studies should:

- Develop techniques to assess concepts' business and environmental benefits;

- Test the usefulness of any selection criteria developed;
- Identify successful routes to market for environmental ideas to learn more about the final product development and actual implementation in industry.

This study has shown the benefits of using tools for the facilitation of workshops and ways in which to promote the development of radical environmental ideas. Tools are more likely to be adopted in industry if they can be integrated non-intrusively into existing design processes. The goal for any designer should be to stimulate and structure their design process to ensure that radical ideas for environmental improvement are captured and subsequently taken through to production. Several specific recommendations for future research emerged from this study. The main goal for research in this field is to ensure that the eco-innovation discipline is developed and promoted further. More industrial case studies will help develop these new tools, methods or theories and promote their adoption.

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Appendix 1

BCS four-step model,

showing telecommunication

products and concepts.

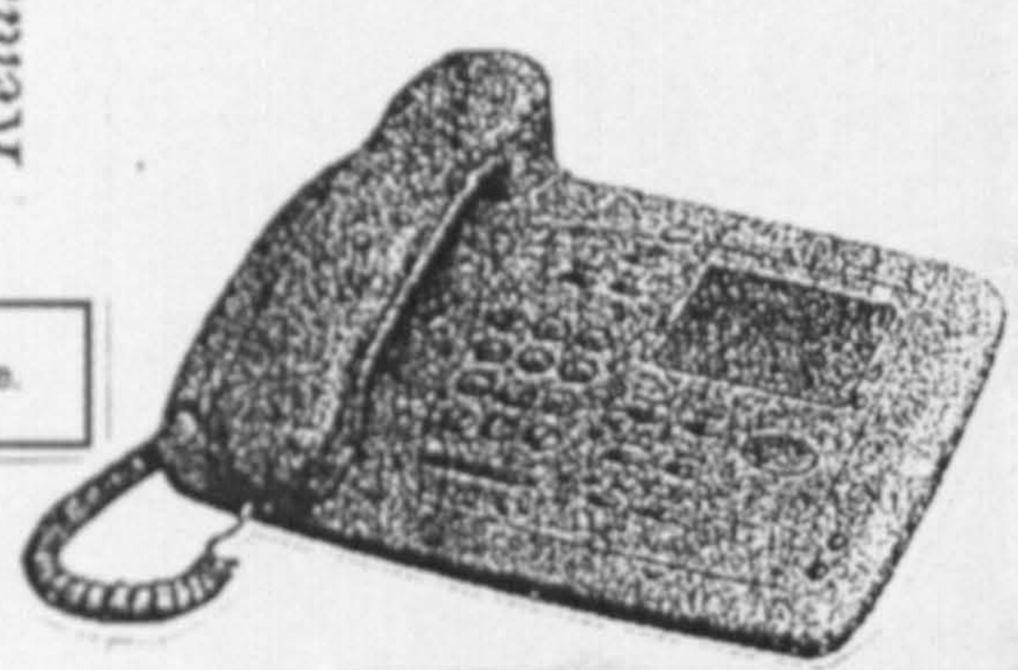
Brezet/Cramers/Stevels: Levels of Eco-Design

Starting Point	Step 1 Development	Step 2 Development	Step 3 Development	Step 4 Development
	Incremental Improvement of Products	(Complete) Redesign of Existing Product Concepts	Alternative Fulfilment of Functionality: New Concepts	Functionality Designs Completely fitting in the Sustainable Society
	Level 1 Development	**Level 2 Development**	**Level 3 Development**	**Level 4 Development**
	IMPROVEMENT 0-2 yrs.	GREEN LIMITS 0-5 yrs.	PRODUCT ALTERNATIVES 0-10 yrs.	SUSTAINABILITY 0-30 yrs.
	Approach Using Existing Eco-design Tools and Techniques on Existing Products.	**Approach** Designing for Factor Change in Environmental Impact: Convergence Energy in Use De-materialisation Alternative Materials Modularity	**Approach** Brainstorming for Products starting from identifying the needs for non-mobile telecommunications products. Home: Privacy & Intimacy Work: Isolation & Concentration	**Approach** Scenario Development for Communication in Sustainable Society.

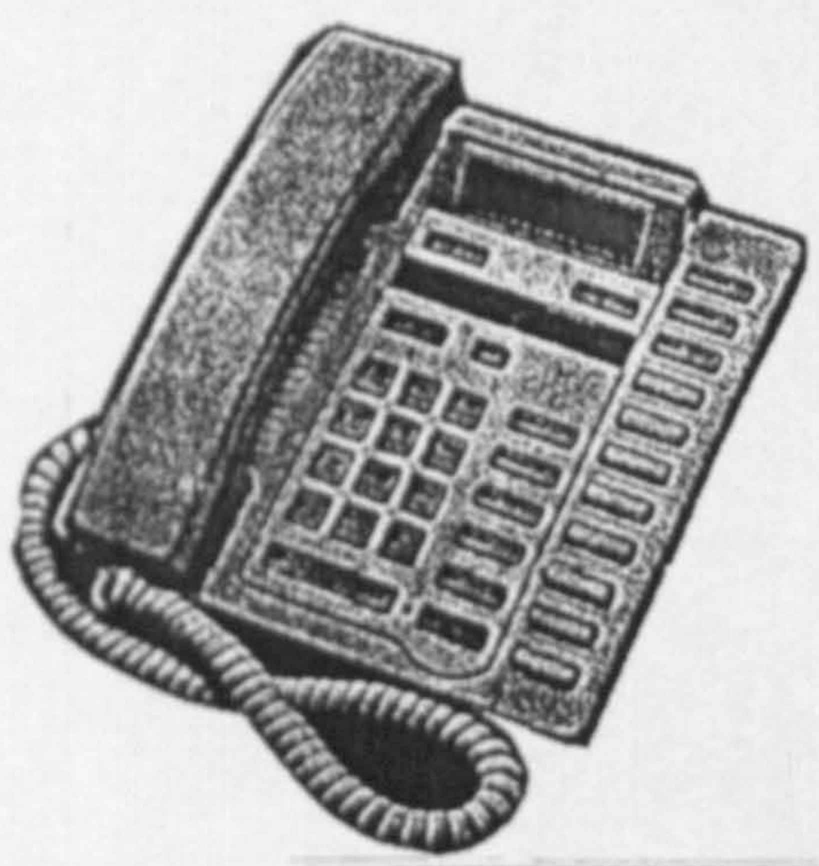
Starting Point

BT
Telephone Handset for Home or Office.

Level 1



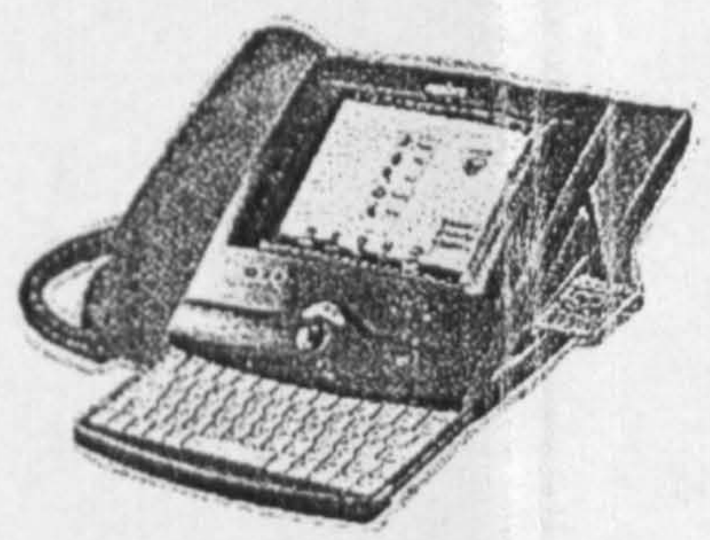
Nortel
Green Phones



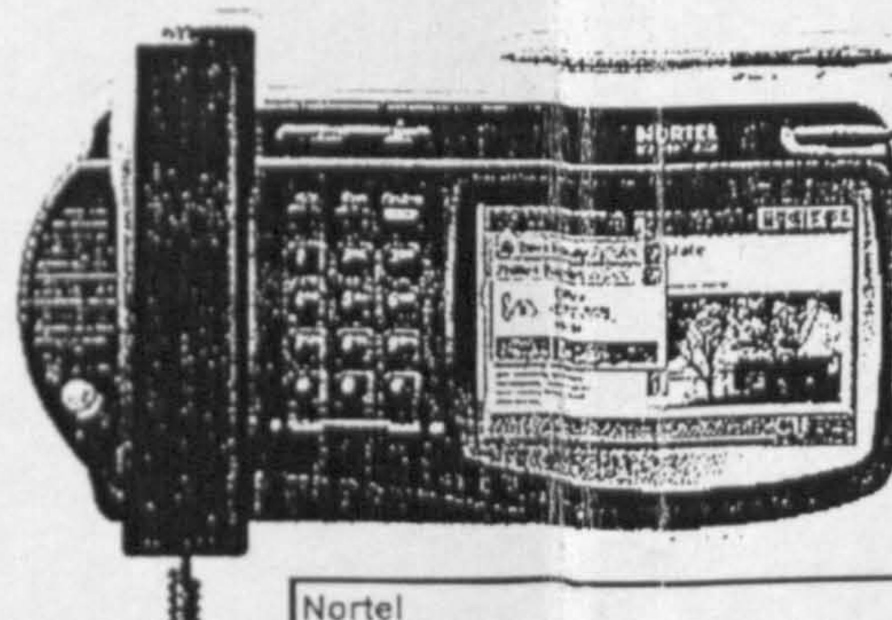
Nortel
Lead-free Phones

Level 2

Nortel
Power-touch: e-mail, fax, phone: convergence and modularity



Alcatel
Internet-station phone: convergence

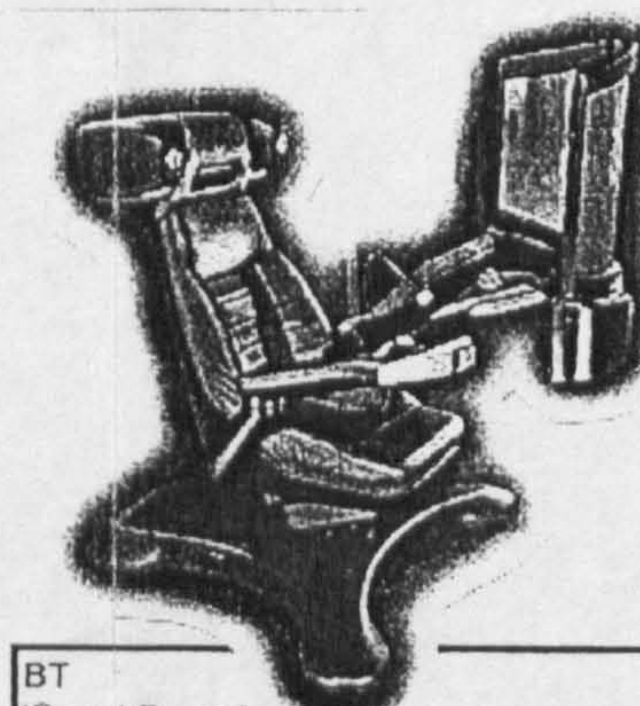


Nortel
Advanced Product Convergence: Internet, e-mail, fax, video & answer phone, computing power.

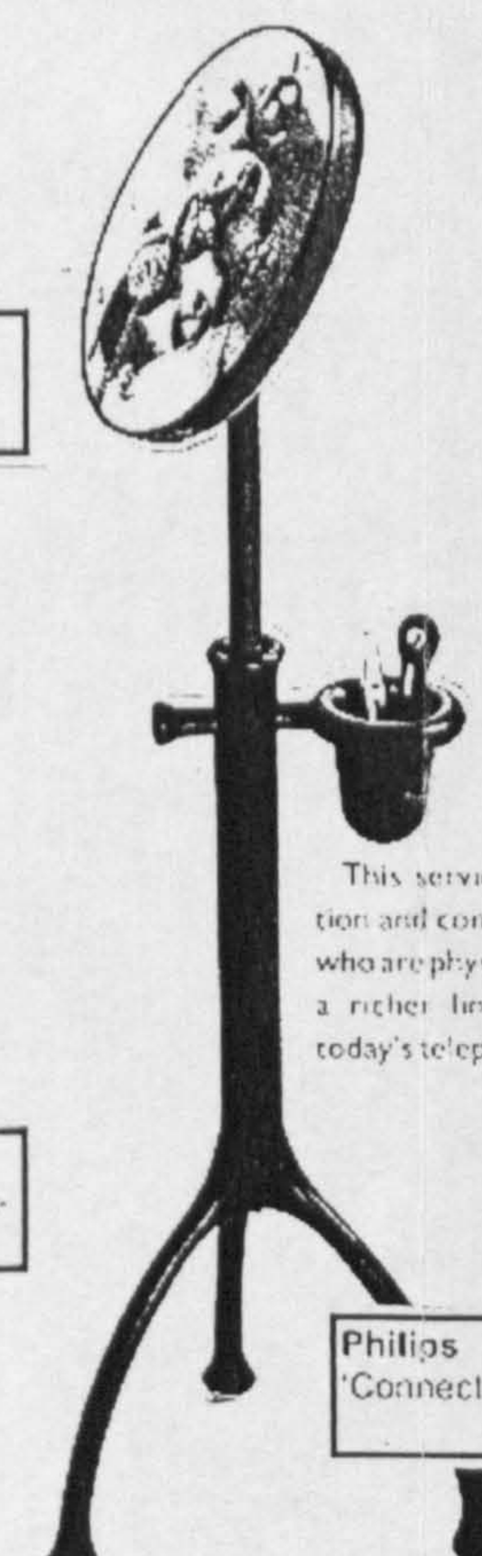
Level 3

SmartSpace

SmartSpace - BT's vision of the personal working environment of the future.



BT
'Smart Space'



connective c ning

socialising on the net

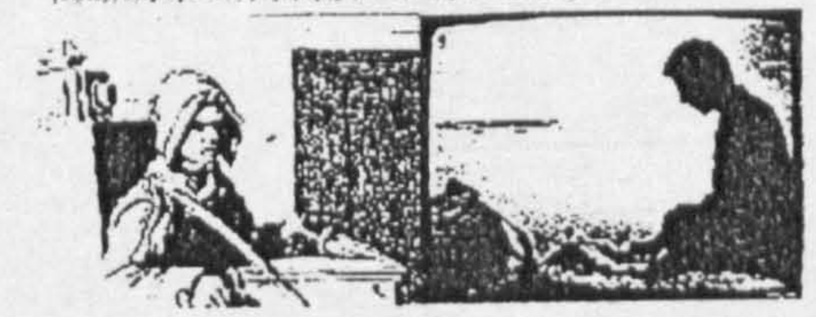
This service enhances communication and connections between people who are physically far apart. It provides a richer link than is possible with today's telephone

Philips
'Connective Socialising'

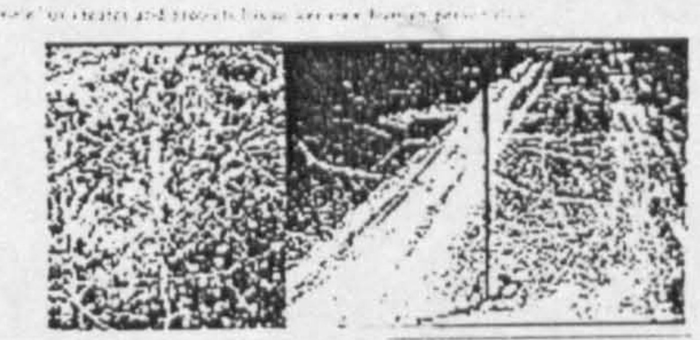
Level 4

The Non-office office New working communities

Nomad office



Virtual office



The Solid Side
'The Non-office office: New working communities'

The home workshop

The Solid Side
'The "living" room'

Appendix 2

Quotations providing an overview of terms most commonly used.

Design for Environment (DfE)	
'the systematic consideration of design performance with respect to environmental, health and safety objectives over the full product and process life cycle'	(Fiksel, 1995)
'A robust DfE approach is one that blends creative excellence, innovation and technical rigour with a view to fearlessly pursuing major environmental and functional objectives.... DfE provides a unique opportunity to make critical interventions early in the product development process and eliminate, avoid or reduce downstream environmental impacts'	(Lewis & Gertsakis, 2001)
Environmentally Conscious Design (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...design considerations are [environmentally] flavoured from the very conceptual stages so that the product is developed in an environmentally conscious manner...'	(ECO2-IRN, 1995)
Ecodesign	
'Ecodesign implies the need to find the right balance between ecological and economic requirements while developing products... the aim is to produce products with the lowest possible environmental burden at all stages of the product life-cycle.'	(Brezet & Van Hemel, 1997).
'the overall goal is to minimise the consumption of natural resources and energy and the consequent impact on the environment while maximising the benefits for customers.'	(Tischner & Charter, 2001)
Green Design	
'the development of products taking account of their impact on the natural environment – as well as the more usual factors such as performance, aesthetics, cost, safety, etc.'	(Roy et al., 1996)
'A green design can contain one or a number of single actions that go towards altering the product's environmental impact'	(ECO2-IRN, 1995)
'designers must design for green markets and future legislative demands whilst maintaining the 'usual' criteria of good design.'	(Burall, 1991)

Life-Cycle Design (LCD)	
'the application of life-cycle assessment (LCA) concepts to determine what a product contains, how it was produced, how it will perform, and what will be left after its useful life is expired.'	(Shapiro & White, 1997)
'... a design approach with focus on Cradle-to-Grave to ensure that potential environmental impacts are identified and eliminated or reduced.'	(Lamvik, 2001)
Sustainable Design	
'Sustainable design is concerned with balancing economic, environmental and social aspects in the creation of products and services.'	(Tischner & Charter, 2001)
'sustainable design begins to address the bigger picture by considering collectively some of the harder questions such as need, equity, ethics, social impact and total resource efficiency and thus the role of design in achieving inter-generational equity.'	(Lewis & Gertsakis, 2001)
Eco-innovation	
'is the development of new products and processes which provide customer and business value but significantly decrease environmental impacts'	(Fussler & James, 1996)
'eco-innovation is about developing more eco-efficient products or services by stimulating an organisational process or individual creativity'	(Charter & James, 1997)
Industrial Ecology	
'Industrial Ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution.'	(Graedel & Allenby, 1995)
'Industrial Ecology aims at identifying and stimulating the interdependencies between the value chains (network of suppliers and consumers) of different products over time. Focuses on designing product systems with a cradle-to-cradle approach.'	(Lamvik, 2001)
Sustainable Development	
'Sustainable Development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations'	(Brundtland, 1987)
'These principles [of sustainable development] embrace social and ethical as well as economic and environmental dimensions: for example... balance economic development with environmental protection,...improve 'quality of life' and ...[ensure] social justice and the rights of future generations.'	(Tischner & Charter, 2001)

Appendix 3

Sample transcript of interview with TRIZ practitioner, referenced in section 6.6.

Name:

Ian Mitchell

Date:

15 May 2001

Time:

15:00 (GMT) (lasting one hour)

What did you call this project?

Edge Suck-off project, but I didn't really put an environmental aspect on that. I wasn't specific about the system that was removed and what that involved. (could put a note together for you on what power was saved exactly)

'Well, actually the environmental angle would given me leverage to use TRIZ more often'

How was the project initiated?

The driving force was poor quality, to start with because we had an issue with this system which wasn't performing very well. Started looking at why and we found out that there were other things that needed looking at in the system. We found that we were putting a lot of energy into the system in order to remove an excess (waste). We had to find a cheaper way to handle the waste. This was done by removing most of the system - Trimming techniques from TRIZ and reverse to a very simple physical effect (TRIZ). Energy consumption could have been a driving force in the project, but less so than projects now perhaps).

Can you describe the environmental drivers in the (many) project?

About the Climate Change Levy, it is going to cost us a considerable amount of money, because we use quite a lot of energy. So we are looking at ways to reduce our energy consumption. The upcoming legislation is causing us to look closely at potential energy saving in the process. What we are doing is looking at lots of systems which run 24/7, and we're looking to see if we can introduce inverters onto them so we can actually drop the system performance when it is not in use. Especially applicable to the big air-handling (1000 m3 per hour) equipment, reducing hot-air emissions into the atmosphere. Also applicable to (hot water) the chlorifiers, switching off or putting inverters on the pumps to reduce energy consumption and capture wasted heat.

We have a fairly good idea how much the Climate Change Levy is going to cost us. We recon it is going to cost us in excess of ...(not quotable). That is a big drive, to try and make savings of that kind of level.

We have looked at a wide range of opportunities:
Selling energy back to the grid, harnessing energy from excess heat using combined heat power units.
Re-circulating excess heat from our plant.
Got close to building our own power station, and selling extra-energy back to the grid.
Joint venture with one of the generating companies, lease them the land, they build the power station, and get reduced rate electricity.

What aspect of the project was environmentally motivated?

Well, it wasn't to start with. I mean we a started out to solve a particular problem but we found we solved it much more drastically then we thought we would. The knock on effect was removal of various heating (2 heated vessels, 50°C re-circulating system) and pumping components (2 pumps, 2.2 KW motors, running 24 hrs a day, 12/14 days) and a compressed air supply (minor a few psi of air, out of main system, like a small leak) from the system.

Q: are they just cost related savings?
Well yes, we look to save money where we can. If you can take two motors out of a system, that will have an effect. We look very closely at cost all the time, having said that, I would say that we are a fairly environmentally friendly out-looking company. Some of the chemicals we deal with are fairly nasty and we wouldn't want to be seen to be polluting the place.
We would like to believe that we are environmentally friendly, it does go that far. Although it's not particularly relevant to what we are talking about: we actually pump back cleaner water into the brook than we take out. We are very careful, the last thing we want to do is pollute anywhere with silver.

ISO 9002- accredited. Mainly affects the quality systems, not all the processes are accredited.

Could they or were they organised as super-system, system and sub-systems problems?

Yes we did move up and down a hierarchy of the problem, because what we had to start with:
How to improve separation of fluid, then we looked at the system as a whole, removed most of the elements of that system and then we went back down to the component level.

We asked ourselves entirely the wrong question to start with. (How to improve separation of fluid), that wasn't where the problem lay....
We were not using the system to its best effect. We had all the components needed but we weren't using them properly.

How would you describe the development process followed during the project?

(Described in the paper) First of all we looked at the (quality) problem and the system itself (function analysis: drawing all the useful and harmful effects in the group)
Then we sat down and said what is this system meant to be doing?

Then we looked at trimming bits out of the system and whether it would retain its' function (trimming tools). Started removing the least useful bits from the system. Can the system still perform its function. Moving the system towards 'ideality'.
They used the invention machine software for this. We were starting to put values in the function analysis diagram and the software started to make suggestions about what would be the least useful part of the system. The further the component is away from the product of the system, the higher the rank is, that is the place where it will start to trim first.

The software helped them (as in experienced TRIZ users to follow a sequence) by starting to ask them to remove things that they thought was fundamental to the system. Which was when they started to realise that the main function of the system was to remove the extra emulsion the rest of the system was superfluous. The software drove us to ask those fundamental questions.

Together they (the TRIZ group) came up with a solution that would still allow the reduced system to perform its function. How could we use the nozzle, the emulsion and water to remove the emulsion from the base?
We used the effects database and 'hard-slog'. We just looked through dozens of effects.

(1) Can you name the stages of your development process?

We did it in three stages, but I didn't write this in my paper.

His group has written their own process (used it a couple of times, not in the form of a flow chart yet) which they try to follow because they found ARIZ really difficult to work with. He looked at the different versions of ARIZ and considered what is was that worked best.

1. Problem definition (functional analysis, S-fields (because there were 2 stages to the problem)
Contradiction matrix (to see if there is anything obvious that we are missing, if there is a contradiction there, because sometimes you don't have a contradiction) but we

look at the matrix and see if a contradiction that we can put to the matrix, that is a fast process. A lot of TRIZ people won't use the matrix anymore because it is too abstract for them (TRIZ experts say: 'old hat, Su-field analysis is what to use').

(3) Which people are involved?

The whole TRIZ group sat down which was 6 or 7 of us. To work on the initial problem definition (analysis). And then 2 of developed the problem to the point where we had removed all the systems but we knew we had to keep part of the system so as not to loose the functionality. And then we involved the TRIZ group again, which was when we came up with the final solution.

Do you have a standard pre-determined process for all your projects?

Yes, this is a standard process: group explore, small team (to take it on) and back to the group.
As a group they never use the software (better for individuals) and they use the software rarely now. We do when we are looking for effects. I use it for drawing function diagrams, draw a big one with the group on paper.

Is it an iterative process? Where?

Yes, it is an iterative process. What I try to get people to do is as we use the various tools, scribe the ideas and drop back into the process go into the next tool. The checklist is just a reminder of how you go through things, very crude ARIZ.

We go back and re-look at things, especially if you have to re-define the problem, but we haven't mapped it out as an iterative process.

How did this environmental project differ from other projects?

I don't think so because if you performed functional analysis: you would have a product like 'clean environment' and all around you would have components that interact with that environment and have a 'harmful' effect or are 'insufficient' in what they do (for example a filter that isn't cleaning the air that you are putting out sufficiently).You would have a box with a description of the component and then you'd have red arrow ('harmful' effect) to a box with 'air' in it.

Appendix 4

Master copy of step-by-step task booklet for experiment conducted in June 2001.

Step 1 5 min.

Step 2 30 min.

Step 3 20 min.

Step 4 15 min.

Step 5 5 min.

Step 6 30 min.

Step 7 15 min.

Task Booklet

Design your logo and name (20 min.)

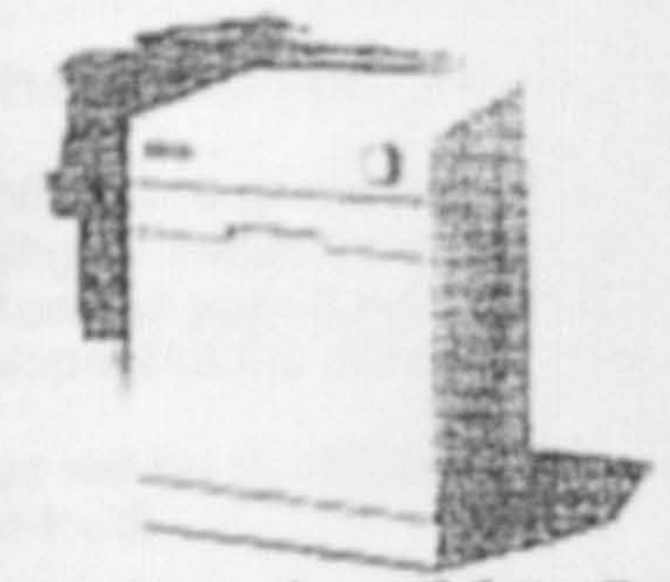
Look through the magazines and cut out two or three pictures that relate to your design interests in some way or simply something that catches your eye.

Put your pictures together and paste them on your mounting board.

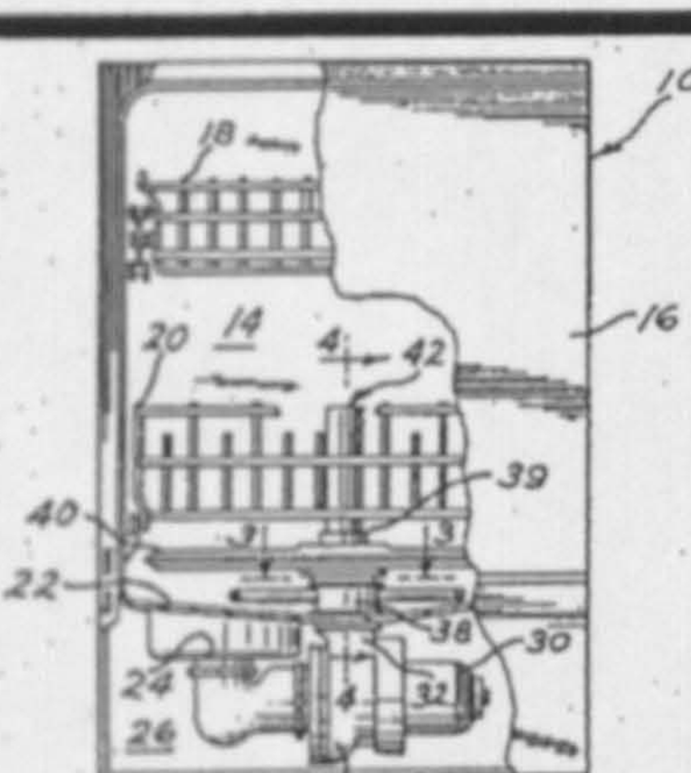
Based on your picture board, brainstorm a name and company logo for your newly formed design consultancy.

Draw your logo and company name on an A4 sheet.

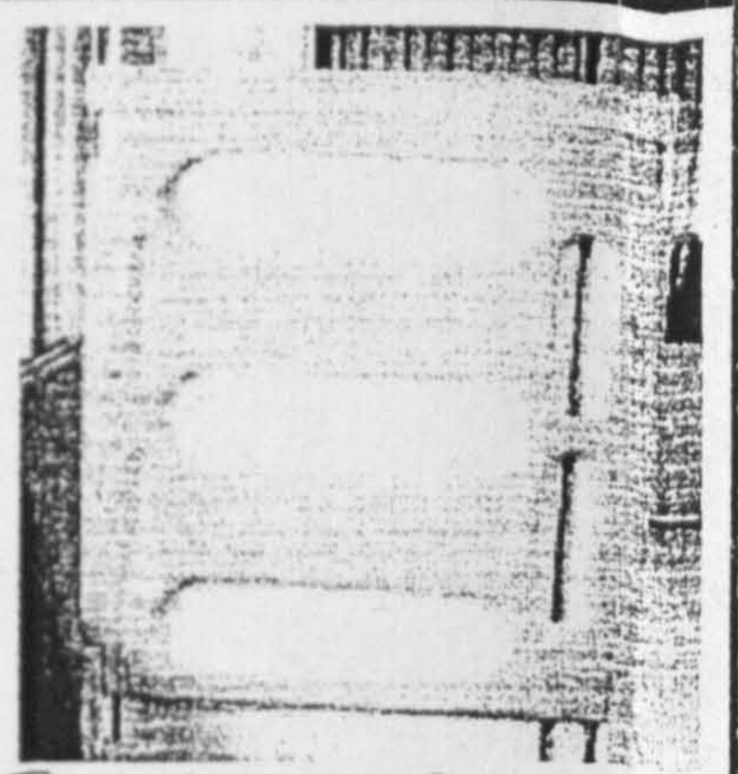
Sketch area



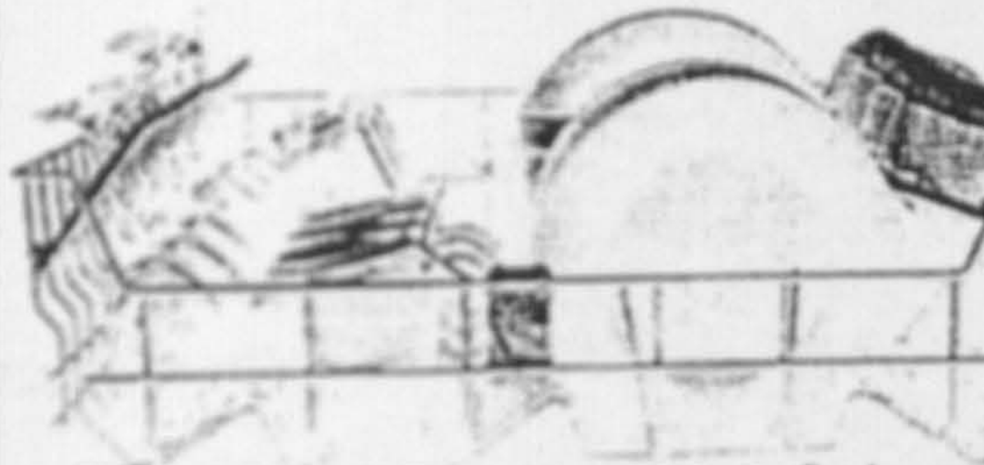
FINISHED PRODUCT CONCEPT



INTERNAL 28 DETAILS



PACKAGING CONCEPT



DISHRACK DESIGN.

INTERFACE CONCEPT

Product concept

Product could be launched in:

☑ 0-2 years time ☐ 2-5 years time ☐ 5-10 years time ☐ 10-30 years time

Give a factual description of the product

THIS DEVICE AUTOMATICALLY CLEANS DISHES BY APPLYING DETERGENT AND HEATED WATER. THE WATER AND DETERGENT ARE SPRAYED ONTO THE DISHES UNDER PRESSURE, THEREBY PRODUCING AN ADDITIONAL CLEANING ACTION.

DIMENSIONS (H×B×D): 0.85 × 0.60 × 0.57 (m) WEIGHT: 30 (kg)

Give a promotional description of the product

"GLOBAL DISHWASHER" FROM DISHLEX

THE GLOBAL INCLUDES SOME OF THE MOST ADVANCED DESIGN AND ENGINEERING AND SETS NEW WORLD STANDARDS IN EFFICIENCY, PERFORMANCE AND STYLE

DISHLEX HAS A 50-YEAR TRADITION OF INNOVATION, ANNUAL SALES OF £315 MILLION AND EMPLOYS 4800 PEOPLE

Product details

List possible components, material types and estimate their weights or volumes

WASHING CHAMBER, STAINLESS STEEL, 5(kg)

DOOR & OUTER CLADDING, ENAMELLED STEEL AND GLASS-FIBRE INSULAT. 15kg

UPPER & LOWER DISHRACKS; PLASTIC COATED STEEL, 1kg

SPRAY ASSEMBLY & MOVING PARTS, ABS/NYLON 2.5kg

MOTOR STEEL & COPPER 5kg

HEATING ELEMENT, CIRCUITRY, ETC

List possible production processes involved

INJECTION MOULDING, RESISTANCE WELDING, MANUAL ASSEMBLY. POWDER COATING, OVEN ENAMELING

Distribution

Describe the transport and packaging required for the product or service provision

THE PRODUCT IS PRODUCED IN NEW SOUTH WALES, AUSTRALIA FOR THE AUSTRALIAN AND NEW ZEALAND MARKET.

A REUSABLE EPS BOX HAS BEEN DEVELOPED. IT REPLACES THE SINGLE-USE FIBREBOARD WITH FOAM INFILL.

AFTER DELIVERY, THE EPS BOX CAN BE DISASSEMBLED AND RETURNED TO THE FACTORY FOR RE-USE

Use of product or service

Describe the users interface with the product or service and the consumables

THIS DEVICE CONTAINS 2 DISH BASKETS WHICH ROLL OUT AND ARE STACKED MANUALLY BY THE USER. THE USER FILLS THE DETERGENT DISPENSER BEFORE THE WASH AND CLEANS THE SUMP FILTER AFTER SOME WASHES. RINSE AID AND SALT (WATER SOFTENER) NEED TO BE KEPT TOPPED UP.

Product Life-time

Estimate the Life-time of the product or service

11 YEARS

Project the maintenence, repair needed for the product or service

THE MAJORITY OF MACHINES WILL HAVE UNDERGONE AT LEAST ONE REPAIR JOB AT THE END OF THEIR LIFE.

HOME MAINTANENCE INCLUDES: CLEANING OUT FILTERS, DE-SCALING, CLEANING OUT BLOCKED SPRAY ARMS.

End of Product life

List toxic components, parts to be re-used, recyleable materials, estimate proportion by weight to land-fill.

THE MOST TOXIC COMPONENT: ELECTRONIC CONTROL CIRCUITRY.

PLASTIC COMPONENTS HAVE BEEN CODED FOR RECYCLING

NUMBER OF DIFFERENT MATERIALS HAS BEEN REDUCED

OVERAL WEIGHT REDUCED BY 7(Kg)

TAKE-BACK SCHEME HAS BEEN ORGANISED AND PRODUCT IS LARGELY RECYCLEABLE.

1 Task Introduction (5 min.)

The task is to explore domestic dishwashing and generate solution concepts for environmental impact reduction. These solution concepts might be new product or service concepts which either replace the current product model or which change the users' behaviour.

This research project looks at how the 'steps' effect the way you generate ideas, so it is important to feedback as much information about your thoughts and ideas as possible.

Please use the sheets, forms and post-it notes to record your ideas during the different parts of the session.

- When you are using blank sheets of paper, put the number of the 'step' your are working on inside the small circle.
- Keep all post-it notes used, collect them at the end each step and put them in an envelope. Put the number of the 'step' your worked on inside the small circle.

Your activities will be recorded by the cameras, so make sure you speak any queries or problems out-loud.

During the workshop you will be asked to fill out two idea description forms.
The example on the opposite fold-out shows how it could be filled out for a dishwasher.

2 Problem Statement (30 min.)

Explore the problems around domestic dishwashing.

Individually, write down any problems that occur to you about domestic dishwashing. You may want to use the dishwashing booklet provided for reference.

As a group, review your statements and reach a consensus on an interesting problem theme to explore. Devise a single statement which encapsulates your communal problem theme (box a).

Now create a pair of elements (box b) that best expresses your communal problem theme. The elements should be in problematic relationship with each other, but instead of writing down the relationship words substitute an asterisk.

Examples:

Problem theme

SLUM CLEARANCE CAN BRING DISADVANTAGE TO SLUM DWELLERS.

box a

Pair of elements

SLUM CLEARANCE

*

SLUM DWELLERS

box b

Problem theme

THIS MEANS A CHANGE IN THE SOCIAL LIFE OF WORKERS TO MAINTAIN CONTINUAL AND EFFICIENT PRODUCTION

box a

Pair of elements

SOCIAL LIFE

*

WORKERS

box b

OR

Pair of elements

SOCIAL LIFE

*

CONTINUAL AND EFFICIENT PRODUCTION.

box b

Generate new problem pairs (boxes c) using the stimulus printed on the arrows.

'Antithesis'
Write down a statement which flatly contradicts the existing statement.

'Abolition'
Abolish one of the problem elements and imagine what would replace it.

'Anagram'
Rearrange the letters in one of the problem elements until a word using most of the letters is found.

'Example'
Write a statement which is a specific example of the existing problem theme.

3 Optimistic Solution (20 min.)

Having explored some of the problems, project optimistic solutions for the future of domestic dishwashing.

Explore some optimistic solutions as follows:

1. Looking at your problem pairs imagine and describe the Ideal Final Result to your problem theme. Ideal Final Result is a description of a system that fulfils all functions required (box a) without any impacts (box b).

Examples:

COMMUTING TO WORK.

IDEAL FINAL RESULT

functions
DOOR-TO-DOOR TRANSPORT FROM HOME TO WORK.
box a
impacts
CONJESTED ROADS AND CAR PARKS, POLLUTION, COSTS, TIME LOST TRAVELLING, ACCIDENT RISKS.
box b

LAWNMOWER.

IDEAL FINAL RESULT

functions
NICE LOOKING LAWN
box a
impacts
NOISE, FUEL, HUMAN TIME AND EFFORT, POLLUTION, THROWS OUT DANGEROUS DEBRIS.
box b

2. Generate intermediate optimistic solutions (boxes c) from your Ideal Final Result towards today's solution.

3. Discuss your ideas and distil them into an optimistic product concept.

3 Optimistic Solution (20 min.)

Having explored some of the problems, brainstorm optimistic solutions for the future of domestic dishwashing.

You are probably familiar with the basic rules of 'classical brainstorming':

Suspend all criticism
Quantity is desired (quantity will breed quality)
Freewheeling is encouraged.

Explore some optimistic solutions as follows:

1. Brainstorm initial ideas individually on post-it notes (one idea on each post-it note).

2. Discuss and sort your ideas as a group by placing all your post-it notes on the table and creating categories to group the ideas. Record your categories on a sheet of paper.

3. Identify and expand the interesting idea-areas together, recording all ideas paper.

4. Distil your ideas into a product concept.

4 Optimistic Product or Service Concept (15 min.)

Fill out the idea description form for your optimistic product or service concept, capturing as much detail as possible.

5 Competition Entry requirements (5 min.)

You are now asked to generate a final product or service concept for domestic dishwashing to be entered in a 'sustainable design competition'.

The judges will be looking for evidence of sustainable value in products and services. An overarching theme that will be considered at every stage of the judging is whether the product or service improves the quality of people's lives.

Judges will consider:

1. The overall environmental impact of the final product concept and its contribution to sustainable development throughout its' life cycle.

2. How different the proposed concept is from current domestic dishwashing practises.

3. How much detail has been tackled by the team.

6 Generate Solutions (30 min.)

You have explored some of the problems and defined an optimistic product concept. Now, for your competition entry it is important to tackle some of the more detailed issues that have come up.

You are probably familiar with the basic rules of 'classical brainstorming':

Suspend all criticism
Quantity is desired (quantity will breed quality)
Freewheeling is encouraged.

Brainstorm in the following sequence:

1. Discuss and reach a consensus on the main issues you want to tackle for your competition entry.

2. Brainstorm initial ideas individually on post-it notes (one idea on each post-it note).

3. Discuss and sort your ideas as a group by placing all your post-it notes on the table and creating categories to group the ideas. Record your categories on a sheet of paper.

4. Identify and expand the interesting idea-areas together, recording all ideas paper.

5. Distil your ideas into a final product or service concept.

6 Generate Solutions (30 min.)

You have explored some of the problems and defined an optimistic product concept. Now, for your competition entry it is important to tackle some of the more detailed issues that have come up.

Brainstorm in the following sequence:

1. Discuss and reach a consensus on the main issues you want to tackle for your competition entry.

2. Brainstorm initial ideas individually on post-it notes (one idea on each post-it note).

3. Discuss and sort your ideas as a group by placing all your post-it notes on the table and creating categories to group the ideas. Record your categories on a sheet of paper.

4. Identify and expand the interesting idea-areas together, recording all ideas paper.

5. Distil your ideas into a final product or service concept.

6 Generate Solutions (30 min.)

You have explored some of the problems and defined an optimistic product concept. Now, for your competition entry it is important to tackle some of the more detailed issues that have come up.

Tackle some of the more detailed issues as follows:

1. Discuss and reach a consensus on the main issues you want to tackle for your competition entry (box a).

2. Define your issues as physical contradictions (boxes b)
Physical contradictions are situations where one element (or body) has contradictory, opposite requirements.

Examples include:

Surveillance aircraft should fly fast (to get to the dèstination) but should fly slowly to collect data directly over the target for long time periods.
Software should be easy to use, but should have many complex features and options.
A bicycle chain must be flexible to traverse a loop and rigid to accept high loads from the pedals.

3. Use the separation principles to generate and record some solution ideas (boxes c).
Physical contradictions are resolved by separation of contradictory requirements in time, space or parts.

Examples:

Physical contradiction AIRPLANES NEED LANDING GEAR TO LAND AND TAKE-OFF, HOWEVER IT SHOULD NOT BE PRESENT DURING FLIGHT BE-CAUSE OF DRAG. box b	**Physical contradiction** THE ROOF ON A HOUSE SHOULD PROTECT THE LIVING SPACE FROM RAIN, BUT IDEALLY TRANSPARENT FOR AIR AND SUNLIGHT box b	**Physical contradiction** A BICYCLE CHAIN MUST BE FLEXIBLE TO TRAVERSE A LOOP. AND RIGID TO ACCEPT HIGH LOADS FROM THE PEDALS. box b
Seperation principle ☑ time ☐ space ☐ parts	**Seperation principle** ☐ time ☑ space ☐ parts	**Seperation principle** ☐ time ☐ space ☑ parts
Solution ideas RETRACTABLE LANDING GEAR box c	**Solution ideas** THE ROOF IS LIFTED ABOVE THE HOUSE LEAVING A GAP FOR AIR AND LIGHT, BUT THE ROOF DESIGN DOES NOT LET RAIN IN. box c	**Solution ideas** A CHAIN OF LINKS, IS RIGID ON THE SMALL SCALE BUT IS FLEXIBLE ON THE LARGE SCALE box c

4. Distil your ideas into a final product or service concept.

6 Generate Solutions (30 min.)

You have explored some of the problems and defined an optimistic product concept. Now, for your competition entry it is important to tackle some of the more detailed issues that have come up.

Tackle some of the more detailed issues as follows:

1. Discuss and reach a consensus on the main issues you want to tackle for your competition entry (box a).

Technical contradiction

(good)	(bad)
A PRODUCT GETS STRONGER	BUT IT'S WEIGHT INCREASES

box b

(improving feature)	(worsening feature)
STRENGTH (ROW 14)	WEIGHT OF STATIONARY OBJECT (COLUMN 2)

box c

Inventive principle numbers

40, 26, 27, 1

box d

Solution ideas

TRY LIGHTWEIGHT COMPOSITE MATERIALS (40) OR IS IT POSSIBLE TO REPLACE THE OBJECT WITH AN OPTICAL IMAGE (26).

2. Define your issues as technical contradictions (boxes b)
Technical contradictions can be classical engineering "trade-offs". The desired state can't be reached because something else in the system prevents it. In other words, when something gets better, something else gets worse.

Other examples:
The bandwidth increases (good) but requires more power (bad).
Service is customized to each customer (good) but the service delivery system gets complicated (bad.)

3. Try to match improving features to the worsening features on the contradiction matrix provided (write them in box c). Using the matrix you can now identify numbers for the principles of invention that may help you to solve your contradictions. The numbers are contained in the cell at the intersection of that row and column (see example on opposite page and write them in box d).

4. Look up the principles of invention the principles booklet provided. Use each principle to generate and record some solution ideas (boxes e).

5. Distil your ideas into a final product or service concept.

7 Final Product or Service Concept (15 min.)

Fill out the idea description form for your final product or service concept, capturing as much detail as possible.

Appendix 5

Sample copies of special forms provided for each tool (reduced in size).

Sketch area

Product concept

Product could be launched in:

- ☐ 0-2 years time
- ☐ 2-5 years time
- ☐ 5-10 years time
- ☐ 10-30 years time

Give a factual description of the product

Give a promotional description of the product

Product details

List possible components, material types and estimate their weights or volumes

List possible production processes involved

Distribution

Describe the transport and packaging required for the product or service provision

Use of product or service

Describe the users interface with the product or service and the consumables

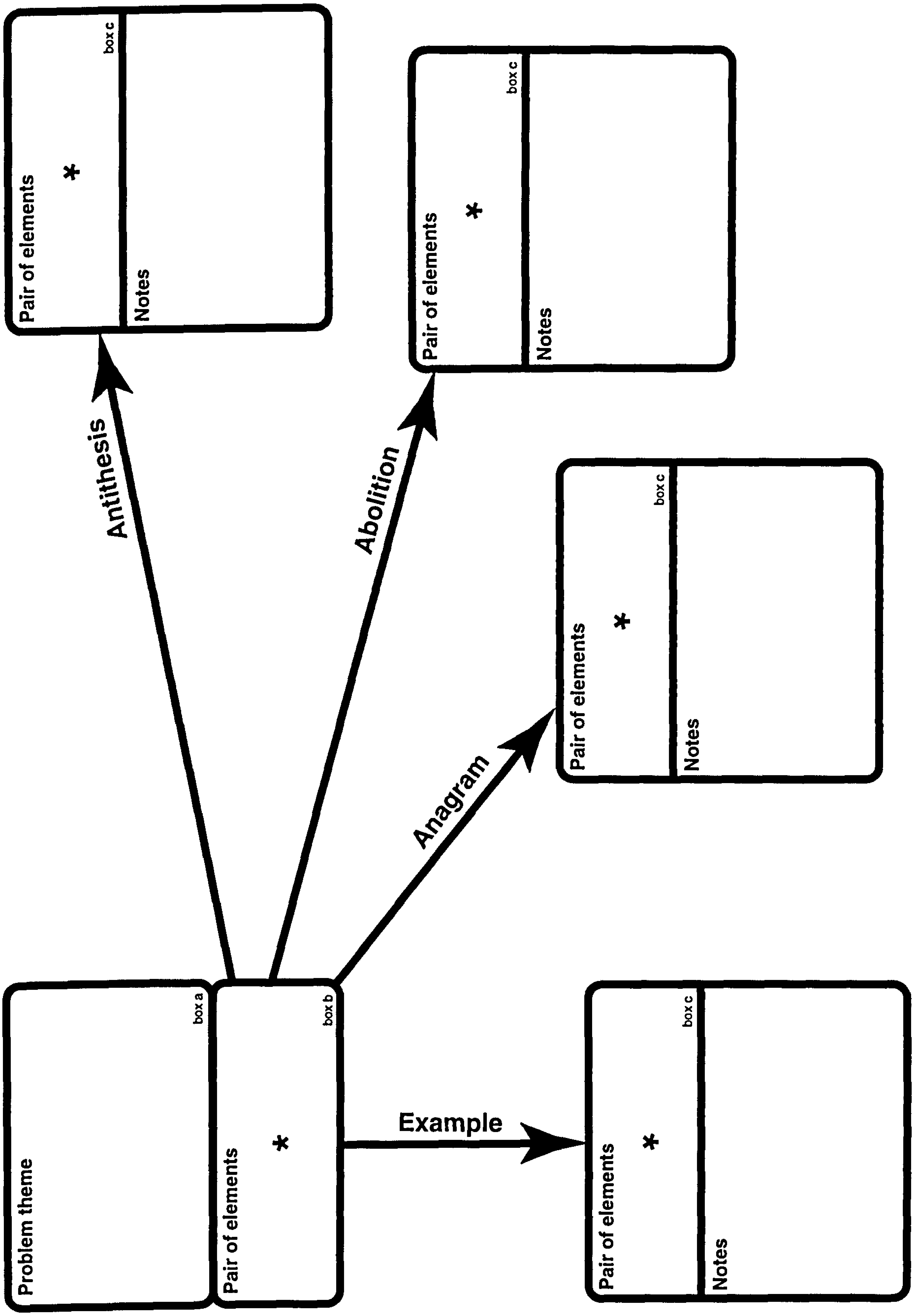
Product Life-time

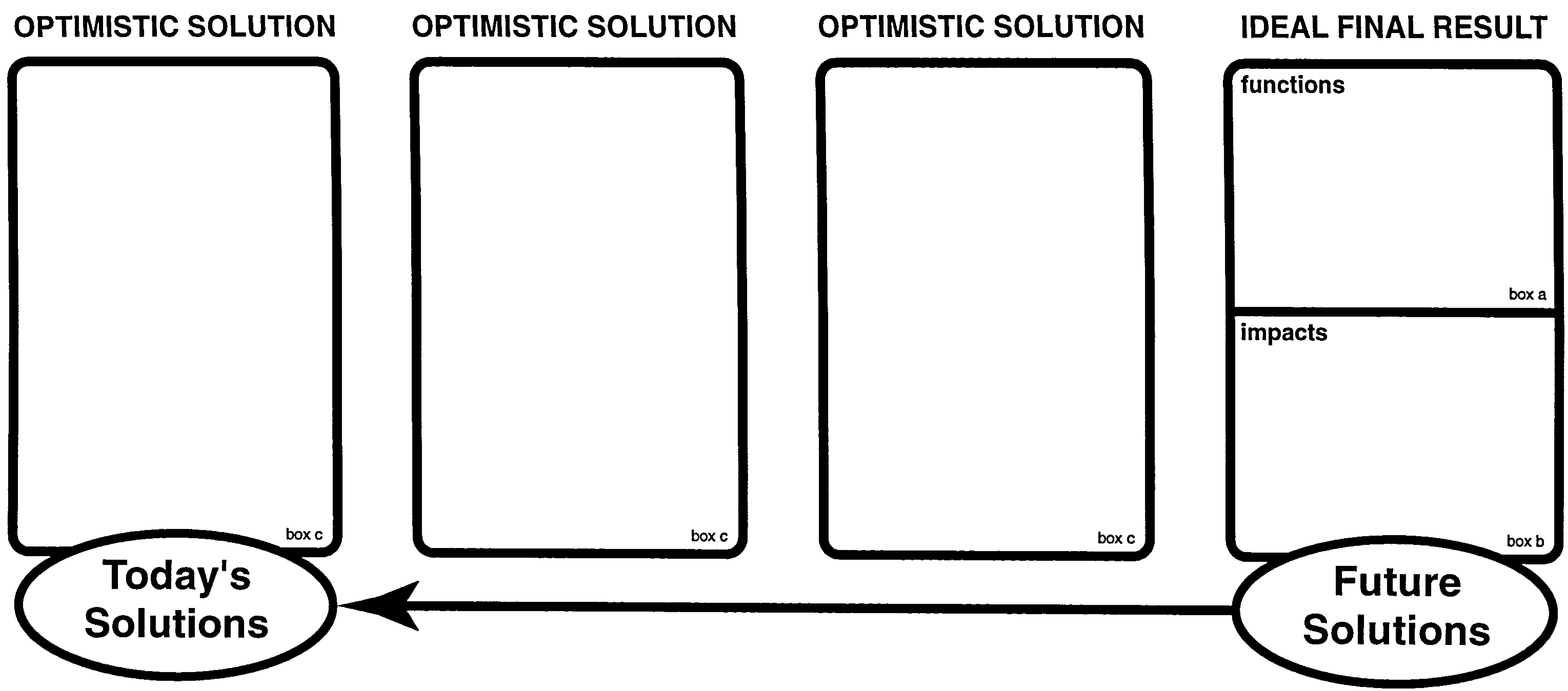
Estimate the Life-time of the product or service

Project the maintenence, repair needed for the product or service

End of Product life

List toxic components, parts to be re-used, recyleable materials, estimate proportion by weight to land-fill.


Problem theme
box a
Pair of elements
*
box b
Antithesis
Abolition
Anagram
Example
Pair of elements
*
box c
Notes
Pair of elements
*
box c
Notes
Pair of elements
*
box c
Notes
Pair of elements
*
box c
Notes


OPTIMISTIC SOLUTION
OPTIMISTIC SOLUTION
OPTIMISTIC SOLUTION
IDEAL FINAL RESULT
functions
box a
impacts
box b
box c
box c
box c
Today's Solutions
Future Solutions

Main Issues		
box a		
Technical contradiction (good) | (bad) box b	**Technical contradiction** (good) | (bad) box b	**Technical contradiction** (good) | (bad) box b
(improving feature) | (worsening feature) box c	(improving feature) | (worsening feature) box c	(improving feature) | (worsening feature) box c
Inventive principle numbers box d	**Inventive principle numbers** box d	**Inventive principle numbers** box d
Solution ideas	**Solution ideas**	**Solution ideas**

Main Issues

box a

Physical contradiction box b	**Physical contradiction** box b	**Physical contradiction** box b
Seperation principle ☐ time ☐ space ☐ parts	**Seperation principle** ☐ time ☐ space ☐ parts	**Seperation principle** ☐ time ☐ space ☐ parts
Solution ideas box c	**Solution ideas** box c	**Solution ideas** box c

Appendix 6

Copy of questionnaire used by expert judges to mark the concepts.

1. Is the concept incremental or radical?
(mark the concept on the 7-point scale between incremental and radical)

☐ ☐ ☐ ☐ ☐ ☐ ☐

incremental: small improvement or re-design of existing dishwasher

radical: a step-change in the way the dishwashing function is fulfilled

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2. At what level does the concept change dishwashing?
(tick one box only)

☐ Sub-system level: new elements or parts of an existing dishwashing device.

☐ System level: a new type of dishwashing device

☐ Super-system level: a different way of domestic dishwashing.

Please indicate the extent to which you agree or disagree with the following statements:
(tick one box only)

	Definitely not	Probably not	Probably yes	Definitely yes
3. The concept is not seen in current versions.	☐	☐	☐	☐
4. The concept could be taken up in existing industry.	☐	☐	☐	☐
5. The concept shows potential to reduce the environmental impact of dishwashing.	☐	☐	☐	☐

---

6. Comment on strengths of the concept

7. Comment on weaknesses of the concept

Appendix 7

Full analysis of the quantitaive data from the TRIZ tools experiment.

	N	Mean	Std Dev	Minimum	Maximum
RADICAL	36	4.44444	1.77996	1.00	7.00
ORIGINAL	36	3.75000	.50000	2.00	4.00
APPROPRI	36	2.38889	.99363	1.00	4.00
EMVREL	36	2.22222	.83190	1.00	4.00
GROUPS	36	3.50000	1.73205	1.00	6.00

- - - - - Kruskal-Wallis 1-Way Anova
RADICAL
by GROUPS groups

Mean Rank	Cases			
10.75	6	GROUPS =	1	A+B1
9.25	6	GROUPS =	2	NoA+B1
24.75	6	GROUPS =	3	A+B2
31.50	6	GROUPS =	4	NoA+B2
19.75	6	GROUPS =	5	A+NoB
15.00	6	GROUPS =	6	NoA+NoB
	36	Total		

			Corrected for ties		
Chi-Square	D.F.	Significance	Chi-Square	D.F.	Significance
19.8649	5	.0013	20.3924	5	.0011

- - - - - Kruskal-Wallis 1-Way Anova
ORIGINAL
by GROUPS groups

Mean Rank	Cases			
16.67	6	GROUPS =	1	A+B1
19.58	6	GROUPS =	2	NoA+B1
19.58	6	GROUPS =	3	A+B2
22.50	6	GROUPS =	4	NoA+B2
22.50	6	GROUPS =	5	A+NoB
10.17	6	GROUPS =	6	NoA+NoB
	36	Total		

			Corrected for ties		
Chi-Square	D.F.	Significance	Chi-Square	D.F.	Significance
5.7920	5	.3270	11.0848	5	.0497

- - - - - Kruskal-Wallis 1-Way Anova
APPROPRI
by GROUPS groups

Mean Rank	Cases			
24.50	6	GROUPS =	1	A+B1
26.25	6	GROUPS =	2	NoA+B1
15.58	6	GROUPS =	3	A+B2
6.75	6	GROUPS =	4	NoA+B2
9.92	6	GROUPS =	5	A+NoB
28.00	6	GROUPS =	6	NoA+NoB
	36	Total		

			Corrected for ties		
Chi-Square	D.F.	Significance	Chi-Square	D.F.	Significance
21.9760	5	.0005	25.8248	5	.0001

- - - - - Kruskal-Wallis 1-Way Anova
EMVREL
by GROUPS groups

Mean Rank	Cases			
21.75	6	GROUPS =	1	A+B1
24.00	6	GROUPS =	2	NoA+B1
15.50	6	GROUPS =	3	A+B2
16.00	6	GROUPS =	4	NoA+B2
6.25	6	GROUPS =	5	A+NoB
27.50	6	GROUPS =	6	NoA+NoB
	36	Total		

			Corrected for ties		
Chi-Square	D.F.	Significance	Chi-Square	D.F.	Significance
15.5203	5	.0084	17.5612	5	.0035

- - Description of Subpopulations - -
Summaries of RADICAL
By levels of GROUPS groups

Variable	Value	Label	Mean	Std Dev	Cases
For Entire Population			4.4444	1.7800	36
GROUPS	1.00	A+B1	3.1667	.7528	6
GROUPS	2.00	NoA+B1	2.8333	1.7224	6
GROUPS	3.00	A+B2	5.5000	1.0488	6
GROUPS	4.00	NoA+B2	6.6667	.5164	6
GROUPS	5.00	A+NoB	4.6667	1.8619	6
GROUPS	6.00	NoA+NoB	3.8333	.9832	6

Total Cases = 36

- - Description of Subpopulations - -
Summaries of SYSTEM
By levels of GROUPS groups

Variable	Value	Label	Mean	Std Dev	Cases
For Entire Population			1.8889	.7475	36
GROUPS	1.00	A+B1	1.6667	.5164	6
GROUPS	2.00	NoA+B1	1.5000	.5477	6
GROUPS	3.00	A+B2	2.3333	.8165	6
GROUPS	4.00	NoA+B2	2.5000	.5477	6
GROUPS	5.00	A+NoB	1.8333	.9832	6
GROUPS	6.00	NoA+NoB	1.5000	.5477	6

Total Cases = 36

- - Description of Subpopulations - -
Summaries of ORIGINAL
By levels of GROUPS groups

Variable	Value	Label	Mean	Std Dev	Cases
For Entire Population			3.7500	.5000	36
GROUPS	1.00	A+B1	3.6667	.5164	6
GROUPS	2.00	NoA+B1	3.8333	.4082	6
GROUPS	3.00	A+B2	3.8333	.4082	6
GROUPS	4.00	NoA+B2	4.0000	.0000	6
GROUPS	5.00	A+NoB	4.0000	.0000	6
GROUPS	6.00	NoA+NoB	3.1667	.7528	6

Total Cases = 36

- - Description of Subpopulations - -
Summaries of APPROPRI
By levels of GROUPS groups

Variable	Value	Label	Mean	Std Dev	Cases
For Entire Population			2.3889	.9936	36
GROUPS	1.00	A+B1	3.0000	.0000	6
GROUPS	2.00	NoA+B1	3.1667	.4082	6
GROUPS	3.00	A+B2	2.1667	.7528	6
GROUPS	4.00	NoA+B2	1.1667	.4082	6
GROUPS	5.00	A+NoB	1.5000	.8367	6
GROUPS	6.00	NoA+NoB	3.3333	.5164	6

Total Cases = 36

- - Description of Subpopulations - -
Summaries of EMVREL
By levels of GROUPS groups

Variable	Value	Label	Mean	Std Dev	Cases
For Entire Population			2.2222	.8319	36
GROUPS	1.00	A+B1	2.5000	.5477	6
GROUPS	2.00	NoA+B1	2.6667	.5164	6
GROUPS	3.00	A+B2	2.0000	.6325	6
GROUPS	4.00	NoA+B2	2.0000	.8944	6
GROUPS	5.00	A+NoB	1.1667	.4082	6
GROUPS	6.00	NoA+NoB	3.0000	.6325	6

Total Cases = 36

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank Cases

7.50 6 GROUPS = 1.00 A+B1
5.50 6 GROUPS = 2.00 NoA+B1
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
12.0	45.0	.3939	-1.0057	.3145

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank Cases

6.00 6 GROUPS = 1.00 A+B1
7.00 6 GROUPS = 2.00 NoA+B1
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
15.0	36.0	.6991	-.6383	.5233

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank Cases

6.00 6 GROUPS = 1.00 A+B1
7.00 6 GROUPS = 2.00 NoA+B1
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
15.0	36.0	.6991	-1.0000	.3173

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank Cases

6.00 6 GROUPS = 1.00 A+B1
7.00 6 GROUPS = 2.00 NoA+B1
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
15.0	36.0	.6991	-.5606	.5751

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank Cases

3.67 6 GROUPS = 1.00 A+B1
9.33 6 GROUPS = 3.00 A+B2
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
1.0	22.0	.0043	-2.7711	.0056

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank Cases

6.00 6 GROUPS = 1.00 A+B1
7.00 6 GROUPS = 3.00 A+B2
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
15.0	36.0	.6991	-.6383	.5233

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank Cases

8.50 6 GROUPS = 1.00 A+B1
4.50 6 GROUPS = 3.00 A+B2
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
6.0	51.0	.0649	-2.3094	.0209

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank	Cases	
7.75	6	GROUPS = 1.00 A+B1
5.25	6	GROUPS = 3.00 A+B2
	--	
	12	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
10.5	46.5	.2403	-1.3693	.1709

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank	Cases	
3.50	6	GROUPS = 1.00 A+B1
9.50	6	GROUPS = 4.00 NoA+B2
	--	
	12	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
.0	21.0	.0022	-2.9665	.0030

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank	Cases	
5.50	6	GROUPS = 1.00 A+B1
7.50	6	GROUPS = 4.00 NoA+B2
	--	
	12	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
12.0	33.0	.3939	-1.4832	.1380

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank	Cases	
9.50	6	GROUPS = 1.00 A+B1
3.50	6	GROUPS = 4.00 NoA+B2
	--	
	12	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
.0	57.0	.0022	-3.2071	.0013

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank	Cases	
7.50	6	GROUPS = 1.00 A+B1
5.50	6	GROUPS = 4.00 NoA+B2
	--	
	12	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
12.0	45.0	.3939	-1.0381	.2992

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test

RADICAL
by GROUPS groups

Mean Rank	Cases	
5.00	6	GROUPS = 1.00 A+B1
8.00	6	GROUPS = 5.00 A+NoB
	--	
	12	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
9.0	30.0	.1797	-1.4751	.1402

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank Cases

5.50 6 GROUPS = 1.00 A+B1
7.50 6 GROUPS = 5.00 A+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
12.0	33.0	.3939	-1.4832	.1380

----- Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank Cases

9.00 6 GROUPS = 1.00 A+B1
4.00 6 GROUPS = 5.00 A+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
3.0	54.0	.0152	-2.7386	.0062

----- Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank Cases

9.25 6 GROUPS = 1.00 A+B1
3.75 6 GROUPS = 5.00 A+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
1.5	55.5	.0043	-2.8147	.0049

----- Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank Cases

5.08 6 GROUPS = 1.00 A+B1
7.92 6 GROUPS = 6.00 NoA+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
9.5	30.5	.1797	-1.4676	.1422

----- Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank Cases

7.67 6 GROUPS = 1.00 A+B1
5.33 6 GROUPS = 6.00 NoA+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
11.0	46.0	.3095	-1.2472	.2123

----- Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank Cases

5.50 6 GROUPS = 1.00 A+B1
7.50 6 GROUPS = 6.00 NoA+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
12.0	33.0	.3939	-1.4832	.1380

----- Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank Cases

5.25 6 GROUPS = 1.00 A+B1
7.75 6 GROUPS = 6.00 NoA+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
10.5	31.5	.2403	-1.3693	.1709

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
RADICAL
by GROUPS groups

Mean Rank	Cases	
4.17	6	GROUPS = 2.00 NoA+B1
8.83	6	GROUPS = 3.00 A+B2
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
4.0	25.0	.0260	-2.2697	.0232

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
ORIGINAL
by GROUPS groups

Mean Rank	Cases	
6.50	6	GROUPS = 2.00 NoA+B1
6.50	6	GROUPS = 3.00 A+B2
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
18.0	39.0	1.0000	.0000	1.0000

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
APPROPRI
by GROUPS groups

Mean Rank	Cases	
8.67	6	GROUPS = 2.00 NoA+B1
4.33	6	GROUPS = 3.00 A+B2
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
5.0	52.0	.0411	-2.3417	.0192

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
EMVREL
by GROUPS groups

Mean Rank	Cases	
8.17	6	GROUPS = 2.00 NoA+B1
4.83	6	GROUPS = 3.00 A+B2
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
8.0	49.0	.1320	-1.7817	.0748

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
RADICAL
by GROUPS groups

Mean Rank	Cases	
3.67	6	GROUPS = 2.00 NoA+B1
9.33	6	GROUPS = 4.00 NoA+B2
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
1.0	22.0	.0043	-2.8017	.0051

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
ORIGINAL
by GROUPS groups

Mean Rank	Cases	
6.00	6	GROUPS = 2.00 NoA+B1
7.00	6	GROUPS = 4.00 NoA+B2
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
15.0	36.0	.6991	-1.0000	.3173

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
APPROPRI
by GROUPS groups

Mean Rank	Cases	
9.50	6	GROUPS = 2.00 NoA+B1
3.50	6	GROUPS = 4.00 NoA+B2
	--	
	12	Total

Exact Corrected for ties

U W 2-Tailed P Z 2-Tailed
P
.0 57.0 .0022 -3.1078 .0019

----- **Mann-Whitney U - Wilcoxon Rank Sum W Test**
EMVREL
by GROUPS groups

Mean Rank Cases

7.83 6 GROUPS = 2.00 NoA+B1
5.17 6 GROUPS = 4.00 NoA+B2
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
10.0 47.0 .2403 -1.3984
.1620

----- **Mann-Whitney U - Wilcoxon Rank Sum W Test**
RADICAL
by GROUPS groups

Mean Rank Cases

4.92 6 GROUPS = 2.00 NoA+B1
8.08 6 GROUPS = 5.00 A+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
8.5 29.5 .1320 -1.5485 .1215

----- **Mann-Whitney U - Wilcoxon Rank Sum W Test**
ORIGINAL
by GROUPS groups

Mean Rank Cases

6.00 6 GROUPS = 2.00 NoA+B1
7.00 6 GROUPS = 5.00 A+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
15.0 36.0 .6991 -1.0000
.3173

----- **Mann-Whitney U - Wilcoxon Rank Sum W Test**
APPROPRI
by GROUPS groups

Mean Rank Cases

9.08 6 GROUPS = 2.00 NoA+B1
3.92 6 GROUPS = 5.00 A+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
2.5 54.5 .0087 -2.7038 .0069

----- **Mann-Whitney U - Wilcoxon Rank Sum W Test**
EMVREL
by GROUPS groups

Mean Rank Cases

9.33 6 GROUPS = 2.00 NoA+B1
3.67 6 GROUPS = 5.00 A+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
1.0 56.0 .0043 -2.9000 .0037

----- **Mann-Whitney U - Wilcoxon Rank Sum W Test**
RADICAL
by GROUPS groups

Mean Rank Cases

5.00 6 GROUPS = 2.00 NoA+B1
8.00 6 GROUPS = 6.00 NoA+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
9.0 30.0 .1797 -1.4805 .1387

----- **Mann-Whitney U - Wilcoxon Rank Sum W Test**
ORIGINAL
by GROUPS groups

Mean Rank Cases

8.08 6 GROUPS = 2.00 NoA+B1
4.92 6 GROUPS = 6.00 NoA+NoB
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
8.5	48.5	.1320	-1.7345	.0828

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank Cases

6.00 6 GROUPS = 2.00 NoA+B1
7.00 6 GROUPS = 6.00 NoA+NoB
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
15.0	36.0	.6991	-.6383	.5233

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank Cases

5.67 6 GROUPS = 2.00 NoA+B1
7.33 6 GROUPS = 6.00 NoA+NoB
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
13.0	34.0	.4848	-.9623	.3359

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank Cases

4.50 6 GROUPS = 3.00 A+B2
8.50 6 GROUPS = 4.00 NoA+B2
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
6.0	27.0	.0649	-2.0350	.0419

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank Cases

6.00 6 GROUPS = 3.00 A+B2
7.00 6 GROUPS = 4.00 NoA+B2
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
15.0	36.0	.6991	-1.0000	.3173

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank Cases

8.67 6 GROUPS = 3.00 A+B2
4.33 6 GROUPS = 4.00 NoA+B2
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
5.0	52.0	.0411	-2.2724	.0231

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank Cases

6.50 6 GROUPS = 3.00 A+B2
6.50 6 GROUPS = 4.00 NoA+B2
--
12 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
18.0	39.0	1.0000	.0000	1.0000

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank	Cases	
7.25	6	GROUPS = 3.00 A+B2
5.75	6	GROUPS = 5.00 A+NoB
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
13.5	43.5	.4848	-.7403	.4591

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank	Cases	
6.00	6	GROUPS = 3.00 A+B2
7.00	6	GROUPS = 5.00 A+NoB
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
15.0	36.0	.6991	-1.0000	.3173

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank	Cases	
7.92	6	GROUPS = 3.00 A+B2
5.08	6	GROUPS = 5.00 A+NoB
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
9.5	47.5	.1797	-1.4500	.1471

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank	Cases	
8.58	6	GROUPS = 3.00 A+B2
4.42	6	GROUPS = 5.00 A+NoB
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
5.5	51.5	.0411	-2.2272	.0259

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank	Cases	
8.83	6	GROUPS = 3.00 A+B2
4.17	6	GROUPS = 6.00 NoA+NoB
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
4.0	53.0	.0260	-2.3467	.0189

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank	Cases	
8.08	6	GROUPS = 3.00 A+B2
4.92	6	GROUPS = 6.00 NoA+NoB
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
8.5	48.5	.1320	-1.7345	.0828

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank	Cases	
4.17	6	GROUPS = 3.00 A+B2
8.83	6	GROUPS = 6.00 NoA+NoB
	--	
	12	Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P

4.0 25.0 .0260 -2.4172 .0156

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank Cases

4.33 6 GROUPS = 3.00 A+B2
8.67 6 GROUPS = 6.00 NoA+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
5.0	26.0	.0411	-2.2445	.0248

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank Cases

8.67 6 GROUPS = 4.00 NoA+B2
4.33 6 GROUPS = 5.00 A+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
5.0	52.0	.0411	-2.1791	.0293

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank Cases

6.50 6 GROUPS = 4.00 NoA+B2
6.50 6 GROUPS = 5.00 A+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
18.0	39.0	1.0000	.0000	1.0000

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
APPROPRI
by GROUPS groups

Mean Rank Cases

5.92 6 GROUPS = 4.00 NoA+B2
7.08 6 GROUPS = 5.00 A+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
14.5	35.5	.5887	-.7379	.4606

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
EMVREL
by GROUPS groups

Mean Rank Cases

8.17 6 GROUPS = 4.00 NoA+B2
4.83 6 GROUPS = 5.00 A+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
8.0	49.0	.1320	-1.8053	.0710

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
RADICAL
by GROUPS groups

Mean Rank Cases

9.50 6 GROUPS = 4.00 NoA+B2
3.50 6 GROUPS = 6.00 NoA+NoB
--
12 Total

U	W	Exact 2-Tailed P	Corrected for ties Z	2-Tailed P
.0	57.0	.0022	-2.9943	.0028

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test
ORIGINAL
by GROUPS groups

Mean Rank Cases

8.50 6 GROUPS = 4.00 NoA+B2
4.50 6 GROUPS = 6.00 NoA+NoB
--
12 Total

Exact Corrected for ties

U W 2-Tailed P Z 2-Tailed
P
6.0 51.0 .0649 -2.3094 .0209

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
APPROPRI
by GROUPS groups

Mean Rank Cases

3.50 6 GROUPS = 4.00 NoA+B2
9.50 6 GROUPS = 6.00 NoA+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
.0 21.0 .0022 -3.0525 .0023

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
EMVREL
by GROUPS groups

Mean Rank Cases

4.67 6 GROUPS = 4.00 NoA+B2
8.33 6 GROUPS = 6.00 NoA+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
7.0 28.0 .0931 -1.8992 .0575

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
RADICAL
by GROUPS groups

Mean Rank Cases

7.58 6 GROUPS = 5.00 A+NoB
5.42 6 GROUPS = 6.00 NoA+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
11.5 45.5 .3095 -1.0693
.2850

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
ORIGINAL
by GROUPS groups

Mean Rank Cases

8.50 6 GROUPS = 5.00 A+NoB
4.50 6 GROUPS = 6.00 NoA+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
6.0 51.0 .0649 -2.3094 .0209

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
APPROPRI
by GROUPS groups

Mean Rank Cases

3.83 6 GROUPS = 5.00 A+NoB
9.17 6 GROUPS = 6.00 NoA+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
2.0 23.0 .0087 -2.7133 .0067

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**
EMVREL
by GROUPS groups

Mean Rank Cases

3.58 6 GROUPS = 5.00 A+NoB
9.42 6 GROUPS = 6.00 NoA+NoB
--
12 Total

Exact Corrected for ties
U W 2-Tailed P Z 2-Tailed
P
.5 21.5 .0022 -2.9677 .0030

	N	Mean	Std Dev	Minimum	Maximum
RADICAL	36	4.44444	1.77996	1.00	7.00
ORIGINAL	36	3.75000	.50000	2.00	4.00
APPROPRI	36	2.38889	.99363	1.00	4.00
EMVREL	36	2.22222	.83190	1.00	4.00
MAKEUP	36	1.50000	.50709	1.00	2.00

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test

ORIGINAL
by IFRTOOL ideal final result

Mean Rank	Cases	
19.58	18	IFRTOOL = 1.00 ifr
17.42	18	IFRTOOL = 2.00 no ifr
	--	
	36	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
142.5	352.5	.5418	-.8535	.3934

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test

RADICAL
by IFRTOOL ideal final result

Mean Rank	Cases	
18.42	18	IFRTOOL = 1.00 ifr
18.58	18	IFRTOOL = 2.00 no ifr
	--	
	36	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
160.5	331.5	.9626	-.0481	.9616

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test

EMVREL
by IFRTOOL ideal final result

Mean Rank	Cases	
14.50	18	IFRTOOL = 1.00 ifr

22.50 18 IFRTOOL = 2.00 no ifr

--

36 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
90.0	261.0	.0224	-2.4231	.0154

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test

APPROPRI
by IFRTOOL ideal final result

Mean Rank Cases

16.67 18 IFRTOOL = 1.00 ifr
20.33 18 IFRTOOL = 2.00 no ifr

--

36 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
129.0	300.0	.3079	-1.1318	.2577

- - - - - Kruskal-Wallis 1-Way Anova

RADICAL
by CONTOOLS contradiction tools

Mean Rank Cases

10.00 12 CONTOOLS = 1 tool B1 used
28.13 12 CONTOOLS = 2 tool B2 used
17.38 12 CONTOOLS = 3 no tool used

--

36 Total

			Corrected for ties		
Chi-Square	D.F.	Significance	Chi-Square	D.F.	Significance
17.9628	2	.0001	18.4399	2	.0001

- - - - - Kruskal-Wallis 1-Way Anova

ORIGINAL
by CONTOOLS contradiction tools

Mean Rank Cases

18.13 12 CONTOOLS = 1 tool B1 used
21.04 12 CONTOOLS = 2 tool B2 used
16.33 12 CONTOOLS = 3 no tool used

--

36 Total

			Corrected for ties		
Chi-Square	D.F.	Significance	Chi-Square	D.F.	Significance
1.2211	2	.5431	2.3369	2	.3108

- - - - - Kruskal-Wallis 1-Way Anova

APPROPRI
by CONTOOLS contradiction tools

Mean Rank	Cases		
25.38	12	CONTOOLS = 1	tool B1 used
11.17	12	CONTOOLS = 2	tool B2 used
18.96	12	CONTOOLS = 3	no tool used

--

36 Total

			Corrected for ties		
Chi-Square	D.F.	Significance	Chi-Square	D.F.	Significance
10.9463	2	.0042	12.8634	2	.0016

- - - - - Kruskal-Wallis 1-Way Anova

EMVREL
by CONTOOLS contradiction tools

Mean Rank	Cases		
22.88	12	CONTOOLS = 1	tool B1 used
15.75	12	CONTOOLS = 2	tool B2 used
16.88	12	CONTOOLS = 3	no tool used

--

36 Total

			Corrected for ties		
Chi-Square	D.F.	Significance	Chi-Square	D.F.	Significance
3.1723	2	.2047	3.5894	2	.1662

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test

RADICAL
by CONTOOLS contradiction tools

Mean Rank	Cases		
7.00	12	CONTOOLS = 1.00	tool B1 used

18.00 12 CONTOOLS = 2.00 tool B2 used
--
24 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
6.0	84.0	.0000	-3.8690	.0001

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**

APPROPRI
by CONTOOLS contradiction tools

Mean Rank Cases

17.58 12 CONTOOLS = 1.00 tool B1 used
7.42 12 CONTOOLS = 2.00 tool B2 used
--
24 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
11.0	211.0	.0001	-3.8841	.0001

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**

RADICAL
by CONTOOLS contradiction tools

Mean Rank Cases

9.50 12 CONTOOLS = 1.00 tool B1 used
15.50 12 CONTOOLS = 3.00 no tool used
--
24 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
36.0	114.0	.0387	-2.1228	.0338

- - - - - **Mann-Whitney U - Wilcoxon Rank Sum W Test**

APPROPRI
by CONTOOLS contradiction tools

Mean Rank Cases

14.29 12 CONTOOLS = 1.00 tool B1 used
10.71 12 CONTOOLS = 3.00 no tool used
--
24 Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P

50.5	171.5	.2189	-1.4855	.1374

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test

RADICAL
by CONTOOLS contradiction tools

Mean Rank	Cases	
16.63	12	CONTOOLS = 2.00 tool B2 used
8.38	12	CONTOOLS = 3.00 no tool used
	--	
	24	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
22.5	199.5	.0029	-2.9195	.0035

- - - - - Mann-Whitney U - Wilcoxon Rank Sum W Test

APPROPRI
by CONTOOLS contradiction tools

Mean Rank	Cases	
10.25	12	CONTOOLS = 2.00 tool B2 used
14.75	12	CONTOOLS = 3.00 no tool used
	--	
	24	Total

		Exact	Corrected for ties	
U	W	2-Tailed P	Z	2-Tailed P
45.0	123.0	.1277	-1.6480	.0994